# APPLIED GEOLOGY.

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*PART II.*

WITH NUMEROUS ILLUSTRATIONS.

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# PREFACE.

THE difficulty of writing a book from the apparently opposite points of view of theory and practice is obvious; but when this apparent opposition is based upon mistaken views as to the relative importance of each, this difficulty is at least some excuse for the attempt to reconcile them.

The reader of these chapters may possibly ask himself the question, "For whom is this book written—for the geologist or the practical man?" The answer is, "For both"—not to teach the practical man his business, which he doubtless knows better than the writer of these pages, nor to teach the scientific student geology; but rather as a suggestive discussion of the intimate connection which undoubtedly exists between geological theory and its application to the industrial pursuits of daily life. The student is often at a loss to understand the real utility, in practical life, of a subject which is so essentially filled with speculative hypothesis as theoretical geology. One reason for this is to be found in the fact that hitherto it has not been the fashion in existing text-books to lay much stress upon the economic aspect of geology. The practical man, on the other hand, too often neglects, even if he does not despise, a mastery of the principles of geology, from a mistaken idea as to its real value. The result has been the comparative neglect of economic geology. The subject is vast, and, within the limits of so small a book, a selection only of

the available material could be utilised. Whether this selection is adequate for the double purpose in view must be left to the reader to decide. It is given to few authors to steer successfully between the two extremes, involving on the one hand an unwieldy volume, and on the other unpardonable omissions. But this difficulty has to be faced by all who attempt the task of compressing an encyclopædic subject into the limits of a few short chapters.

Interest and utility are the ultimate tests of the value of a book; and if these pages should prove of some interest to the student, and of some use, however small, to the practical man, the author's aim will have been more than achieved.

J. VINCENT ELSDEN.

Storrington, 1899.

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## CORRIGENDA.

Page 49, line 8, for *pacas* read *pacos*.

" 52, " 28, for *magnetic chlorite* read *magnetite, chlorite*.

# APPLIED GEOLOGY.

## PART II.

### CHAPTER VI.

*Unstratified Ote Deposits—Fissure Veins—Bedded Veins—Contact Veins—Gash Veins—Stockworks and Carbonas—Pockets in Limestone Rocks—Pockets and Disseminations in Igneous Rocks—General Remarks on Ores.*

*Unstratified Ore Deposits.*—In the previous chapter we considered all those metalliferous deposits which occur in well-defined beds, and which were formed more or less contemporaneously with the strata enclosing them. There is, however, an important class of ore deposits which have been introduced subsequently into the rocks containing them, and which are distinguished by the absence of any distinct bedded arrangement. Although usually obtained by mining, some of these deposits are worked in quarries or open works. They may be classified as follows :—

UNSTRATIFIED ORE DEPOSITS.

| | | *Typical Examples.* |
|---|---|---|
| Veins or Lodes, *i.e.*, deposits in fissures in the country rock. | *a.* Fissure Veins. | Ordinary Mineral Lodes |
| | *b.* Bedded Veins. | Saddle Reefs. |
| | *c.* Contact Veins. | Comstock Lode, etc. |
| | *d.* Gash Veins. | Galena deposits in Limestone. |
| Masses, *i.e.*, irregular deposits filling chambers or pockets in the enclosing rock. | *e.* Stockworks and Carbonas. | Some Tin-stone deposits in Granite. |
| | *f.* Pockets in Limestone. | Cumberland Hæmatite. |
| | *g.* Pockets and disseminations in igneous rocks. | Some Magnetic and Chrome Iron Ores. |

*Fissure Veins.*—Many of the older rocks of the earth's crust are traversed by systems of cracks or fissures which have served as receptacles for the accumulation of various minerals. These fissures generally display a well-marked symmetry, often intersecting to form a network of cracks called a *field of fracture*. The number of fissures in each field of fracture is indefinite, as many as nine hundred being known in the proximity of Freiberg alone. In each field of fracture a certain parallel set of fissures alone are ore bearing. These

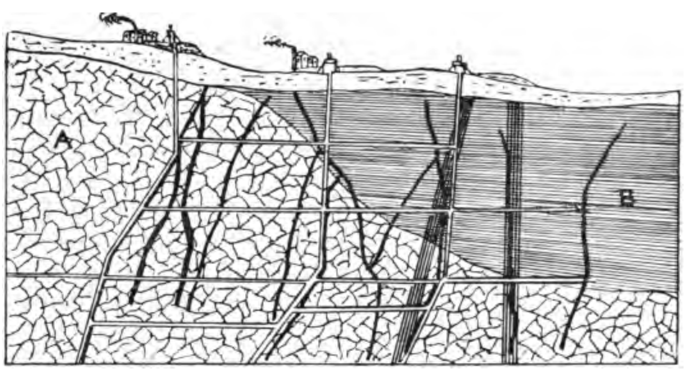


FIG. 58.—SECTION OF A MINING DISTRICT IN CORNWALL.
A, Granite; B, Clay-slate; Black lines, Mineral Veins.

are said to be *right running*, while those which intersect them are termed *counter veins* or *cross courses*. Such conjugate systems of cracks were produced artificially by Daubrée as the result of mechanical force acting upon thick glass plates.

In describing the position of these fissures the same terms are used as have already been described in connection with faults.

In Europe, typical fields of fracture occur in the Erzgebirge and Hartz Mountains, in Cornwall, Bohemia, Hungary and elsewhere. It is probable that such

systems of fissure are abundant in every disturbed area, but it is only where they have become infiltrated with metalliferous ores that they assume economic importance. Under these circumstances they become mineral veins. Fig. 58 represents diagrammatically a portion of a mining area in Cornwall, in which the veins traverse both the granite and the clay-slate.

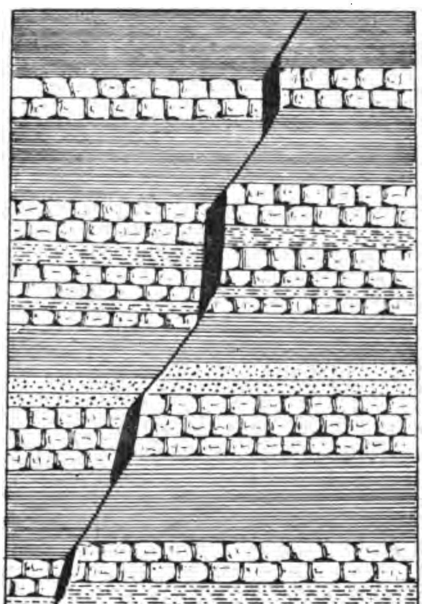

FIG. 59.—VARIATION IN WIDTH OF LODES.

The rock traversed by a vein or lode is called the *country rock*, and upon the nature of this rock will depend the angle which the fracture makes with the vertical, that is, the hade of the lode. This varying angle of fracture has been the chief cause of the opening of the fissure to a sufficient width to admit of the accumulation of ore deposits. For, if we consider

motion to have taken place along an undulating crack, cavities must necessarily be formed by the alternate swelling and contraction of the fissure. This will be evident from the diagram, Fig. 59, showing the variation in width of a lode traversing beds of unequal hardness. Like fault planes, fissures often split up into branches, so that occasionally a branching vein unites


FIG. 60.—BRANCHING VEIN, showing Horse, A.

and encloses a portion of the country rock, called in this case a *horse* or *rider*. (Fig. 60.)

The materials filling the fissure consist of a non-metalliferous portion called *gangue* or *veinstone*, in which the metalliferous portion, or ore, is more or less plentifully disseminated. The gangue is most commonly composed of such minerals as quartz, calcite, fluorspar and barytes, together with portions of the country rock. Occasionally only a single one of these minerals fills the

lode, which is then called *massive*. More commonly the lode has been filled by a succession of layers of mineral matter parallel to the walls of the fissure, and exhibiting a more or less symmetrical repetition on either side, as in Fig. 61. These are termed *banded* or *comby* lodes. *Brecciated* lodes are made up of angular fragments without either symmetry or parallel arrangement.

Cavities, called *drusses* or *vughs*, often occur in veins. These form receptacles in which minerals crystallise

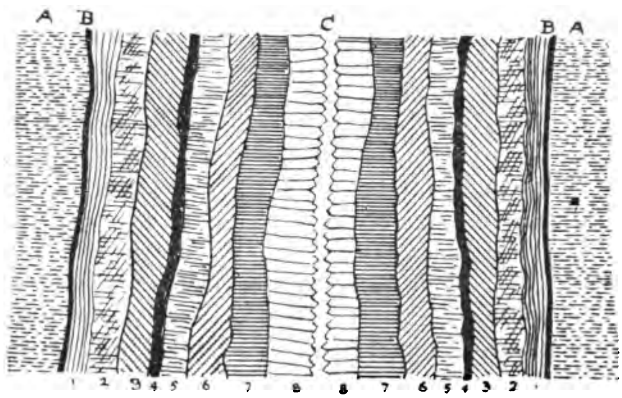


FIG. 61.—SECTION OF BANDED LODE.
A, Country Rock; B, Selvage; C, Comb structure; 1, Pyrites; 2, Calcite; 3, Quartz; 4, Ore; 5, Barytes; 6, Galena; 7, Fluorspar; 8, Quartz.

with more or less perfect forms. The vein is generally separated from the country rock by a layer of clay, called, *selvage* or *flucan*, resulting from mechanical trituration of the walls of the fissure, evidence of movement being often present in the form of *slickensides*, a term applied to the smoothed, polished or striated surfaces sometimes exhibited on the walls of a lode.

The metallic ore is very unevenly distributed in the lode, being sometimes so sparingly present that the lode

is no longer profitable; at other times forming rich deposits of ore for a considerable distance, and constituting what are known to the American miner as ***bonanzas***. These richer portions of a lode are called ***courses of ore*** if they extend in a more or less lateral direction, and ***shoots*** or ***chimneys*** if they extend vertically, while smaller detached patches are termed ***bunches***.

The productiveness of a lode is influenced not only by its hade and strike, but also by the nature of the country rock. As regards the hade, it is usually found that the steeper parts of the lode are richer in ore than the more horizontal parts. As the lode also follows a more or less sinuous line of outcrop, there is a marked tendency to parallelism in the more productive parts. The influence of the country rock is of marked importance in the case of lodes which traverse strata of different kinds. Thus, in Derbyshire, the lead veins in the carboniferous limestone traverse interbedded volcanic rocks, called *toadstones*, in which the galena is generally absent. The *fahlbands* of Norway are belts of decomposed schist, coloured by hydrated ferric oxide, in which the veins contain productive silver ores, the yield being insignificant, except where the fahlbands are intersected. Similarly, at Ballarat, the quartz veins become exceptionally rich in gold where they cross narrow beds of pyritous slates, which are, therefore, known as *indicators*. In Cornwall, again, the killas or clay-slate is separated from the granite by a zone of hornblendic metamorphic rock, the lodes usually yielding tin in the granite, copper in the metamorphic zone, and lead in the clay-slate. At Botallack the same lode repeatedly changes from copper to tin every time the granite is intersected. Examples might be multiplied indefinitely of the intimate relationship between the nature of a lode and its country rock.

There is a considerable variation also in the nature

of the ore as the depth below the surface increases, the pyritic ores of the deeper parts having become oxidised nearer the surface, as has already been noticed in the case of gold, liberated near the surface by the decomposition of its associated sulphides. Productiveness seems to be often affected by the intersection of a lode with other veins, which seem to have acted as *feeders* by increasing the yield of ore near the junction.

The explanation of these peculiarities is still obscure, but of the numerous theories which have been advanced, the following may assist in giving a clearer idea of the phenomena :—

(*a.*) The theory of *igneous injection*, which supposes that mineral veins have been injected by molten material from below, just as dykes have been infiltrated by igneous rock. Undoubtedly some igneous dykes contain disseminated metallic compounds, which may become concentrated by the decomposition of the containing minerals, as in the case of the *mullock* veins of Australia, where decomposed igneous dykes contain gold, silver and quartz. But the nature of the majority of lodes traversing stratified rocks, and especially their marked banded structure, is entirely opposed to the view of their igneous origin.

(*b.*) The theory of *sublimation* of metallic minerals from below has received strong support from the experiments of Durocher, Plattner and Daubrée. Thus magnetite, galena, pyrites and blende, have all been obtained as the result of the artificial sublimation of metallic vapours in glass tubes. Daubrée produced tin oxide artificially by the sublimation of the chloride or fluoride. It is quite possible that some volatile minerals, like cinnabar, may have been formed in this way, but this theory fails altogether to explain many of the complicated phenomena of mineral veins.

(*c.*) The theory of *lateral secretion* ascribes the ore de-

posits to the percolation of water through the country rock, whereby the various metallic compounds have been dissolved and redeposited in the fissures. It is true that the rock-forming minerals contain most, if not all, of the materials which are found in mineral veins, and natural waters often contain appreciable quantities of these substances in solution. This theory also explains the marked variation in mineral lodes as they traverse rocks of different kinds.

(*d.*) The theory of *ascension* of metallic ores in solution from below has the advantage of confirmation by actual observation of deposits now forming by the agency of hot springs. Thus the hot springs of Sulphur Bank, California, deposit silica, pyrites and cinnabar. A similar occurrence is noted at the steamboat springs of Nevada, in the neighbourhood of the Comstock lode, where mining operations in the deeper levels were interrupted by hot springs of the same nature. The ascension theory scarcely explains the influence of the country rock upon the contents of mineral lodes, unless we suppose that the walls of lodes of different mineral composition exercise a selective power upon the precipitation of dissolved metalliferous minerals. On the whole we must conclude that it is impossible in the present state of knowledge to say whence the ores were derived, beyond the generally admitted probability that they have originated from aqueous solutions, the dissolving powers of which have been largely increased by the temperature and chemical composition of the waters.

*Bedded or Segregation Veins.*—Certain veins in stratified rocks follow the direction of the bedding planes. In other respects they resemble the fissure veins described above. Gold-bearing quartz veins, containing also pyrites, blende and galena, such as those found traversing the slaty-rocks of Nova Scotia, are characteristic of this class; while other minerals, such as cassiterite

and chromite, being almost exclusively confined to the igneous rocks, are rarely found under such conditions. An interesting example of this kind of deposit has been described by Mr. E. F. Pittman, as occurring in the so-called *saddle reefs* of Bendigo, Victoria, where the gold-bearing quartz occurs at the axes of the folds of slates and sandstone (see Fig. 62), in which hollow

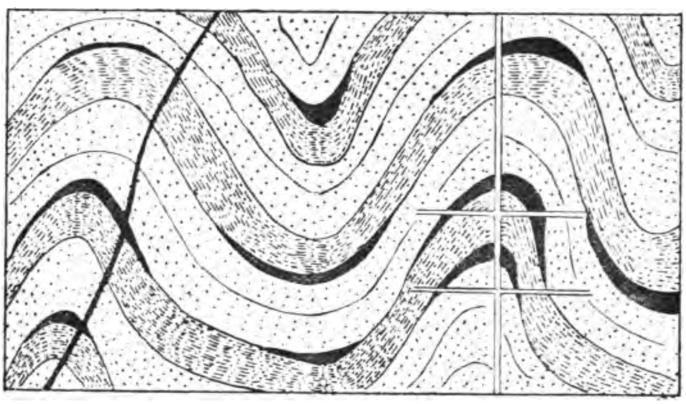

FIG. 62.—SADDLE REEFS, BENDIGO, VICTORIA.

spaces would naturally result from the puckering of the strata. In the hollows thus formed the mineral matter has been deposited by lateral secretion from the country rock.

*Contact Veins.*—In the plane of weakness occurring at the junction of dissimilar rocks, such as eruptive and stratified rocks, mineral deposits are often found. Such veins may also occur at the junction of different kinds of stratified rock, especially when one of these is limestone. Examples of such veins are very numerous, notable instances being found in the specular iron surrounding an intrusive boss of porphyry at Framont in the Vosges Mountains, the native copper occupying

the junction of sandstones and volcanic rock on the south side of Lake Superior, and the silver-lead ores of Leadville, Colorado, marking the junction of porphy-

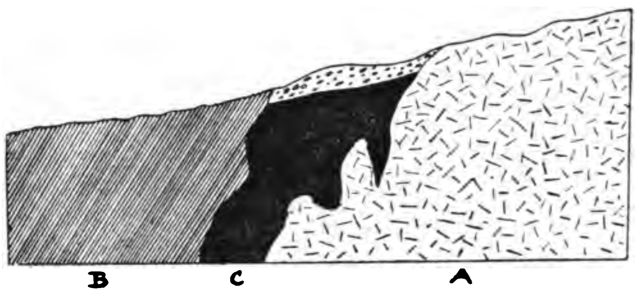


FIG. 63.—SECTION OF CONTACT VEIN, RIO TINTO.
A, Porphyry; B, Slate; C, Pyrites deposit.

ritic rock with limestone. In such cases the mineral solutions may either have ascended from below into the fissured junctions, or they may have been derived by lateral secretion from the igneous rock itself. An illus-

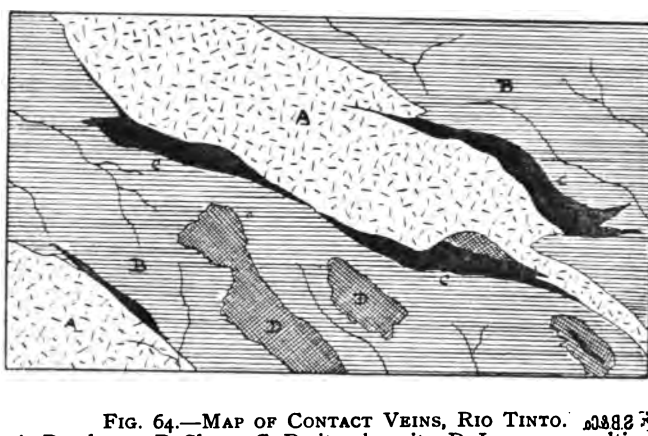

FIG. 64.—MAP OF CONTACT VEINS, RIO TINTO.
A, Porphyry; B, Slate; C, Pyrites deposit; D, Iron ore, resulting from decomposition of C.

tration of this class of vein is given in Figs. 63, 64, showing the mode of occurrence of the famous pyrites deposit of Rio Tinto. The remarkable Comstock Lode, in Nevada, is usually considered to be a contact vein. Fig. 65 shows the position of this lode at the foot of

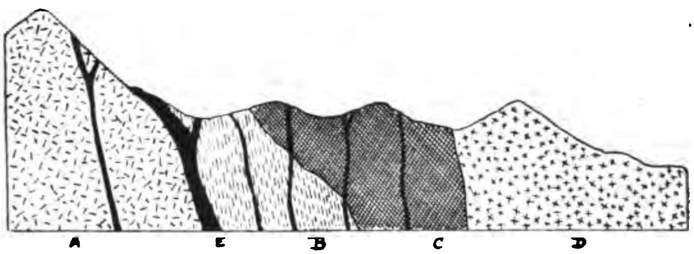


FIG. 65.—THE COMSTOCK LODE, Transverse Section. A, Diorite; B, Diabase; C, Hornblende Andesite; D, Augite Andesite; E, Comstock Lode.

Mount Davidson, where the silver mines, for twenty years, yielded unparalleled results. Fig. 66 is a longitudinal section taken along the lode, and showing the irregular distribution of the ores in rich bonanzas, with


FIG. 66.—THE COMSTOCK LODE, Longitudinal Section, showing *Bonanzas*, A; *Gangue*, B.

barren intervening spaces. The ascent of hot springs in the deeper parts of the mines, and the general appearance of the lode, combined with the absence of any signs of prolonged erosion, point it out as a rare example of a mineral vein of recent origin.

*Gash Veins.*—Limestones are specially liable to contain cavities formed by the dissolving action of percolating water charged with carbonic acid. Such cavities generally represent an enlargement of joints or bedding planes, through which the subterranean water freely percolates. These cavities afterwards become receptacles for the accumulation of ores originally disseminated throughout the neighbouring rocks. In this way were formed the more or less vertical veins of galena,

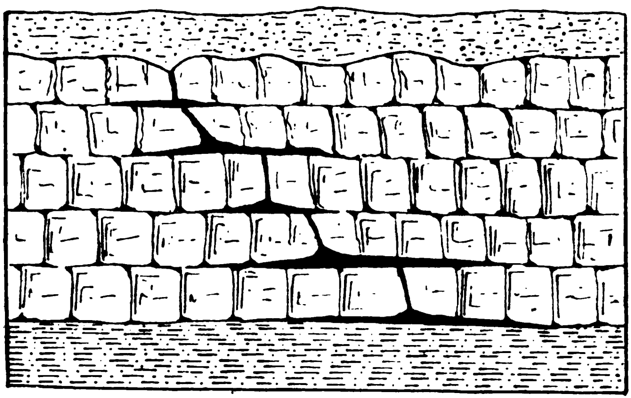

FIG. 67.—GASH VEINS AND FLATS IN LIMESTONE.

which occupy not only the joints in limestone rocks, but are also often connected with horizontal *sheets* or *flats* lying in the bedding planes. The appearance of these deposits is shown in Fig. 67. Such gash veins, as they are termed, being confined to the limits of a single stratum, are never very extensive, and it is doubtful if they should be classed as veins at all.

*Stockworks and Carbonas.*—Occasionally rocks are traversed by a network of such minute veins of ore that the rock itself is mined and crushed. Such string-like

veins are called *stockworks* or *reticulated veins*, an illustration of which is given in Fig. 68. In such cases the whole country rock is usually impregnated with the ore found in the veins. This mode of occurrence is particularly characteristic of tin-stone veins in granite, and numerous examples occur both in Saxony and Cornwall. Somewhat similar impregnations of the country rock are often found in the neighbourhood of small thread-like veins called *leaders* in tin-bearing rocks (Fig. 69). At other times small veins, branching from

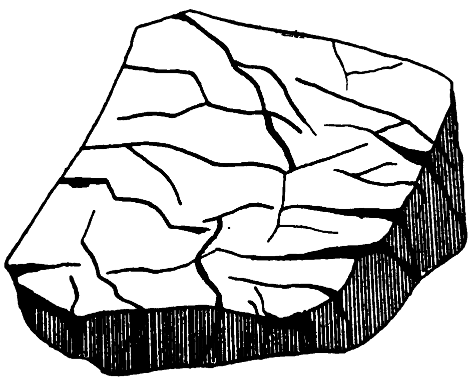

FIG. 68.—STOCKWORK.

the wall of a lode, when followed up, open at length into large irregular accumulations of ore called *carbonas*, which are of a similar nature to the impregnations just described, but situated at a greater distance from the parent vein. Somewhat similar to the above are the *flats* of ore or tin *floors* occasionally issuing from a lode at the junction between the bedding planes of the clay slates in Cornwall, the flats often being more productive than the lode itself.

*Pockets in Limestone Rocks.*—Irregular massive accumulations of metallic ores frequently occupy cavities in

limestone rocks. It is an open question whether the ores have infiltrated into a pre-existing solution cavity in the limestone, as in the case of the gash veins and flats of galena already described, or whether the limestone has been replaced by the ore in solution. The latter view appears to be more probably true, in which

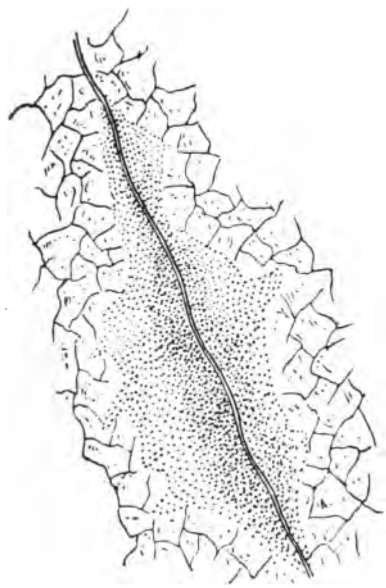

FIG. 69.—IMPREGNATION OF TIN-STONE.

case the term *replacement* deposits would be more appropriate. Their origin is of some economic importance, for solution cavities would only occur in the upper parts of the rock, whereas replacement might take place at any depth. Figs. 70 and 71 represent the pockets of red hæmatite which occur in the carboniferous limestone of Cumberland. Of a similar nature are the brown hæmatite deposits of the Forest of Dean, the

calamine in the carboniferous limestone of Belgium, and the argentiferous galena of Nevada. Silver ores also occur in limestone cavities, a circumstance which may possibly be explained by the solubility of carbonate of silver in water containing carbonic acid, and the replacement of carbonate of lime by this means.*

*Pockets and Disseminations in Igneous Rocks.*—It is easy to understand that certain minerals, such as magnetite, ilmenite, or chromite, abundant in igneous rocks, might become aggregated while the rock was still in a

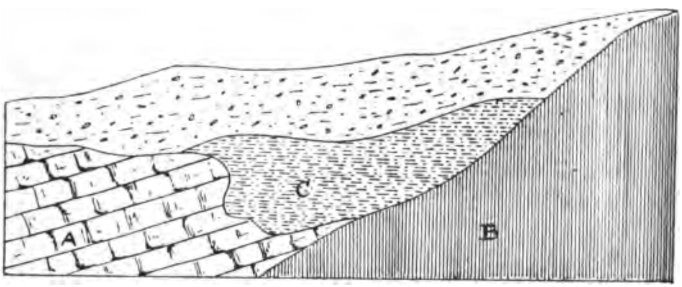


FIG. 70.—HÆMATITE DEPOSITS IN CARBONIFEROUS LIMESTONE.
A, Limestone; B, Silurian strata; C, Hæmatite.

fluid state. This process, which may be termed magmatic segregation, seems likely to have been the origin of the famous magnetite deposits of Scandinavia, as well as to explain the frequent association of serpentine with deposits of chrome iron and nickel or cobalt ores.

An interesting example of a similar nature is seen in the native copper deposits of Lake Superior, where old lava flows occasionally containing amygdaloidal cavities filled with zeolites, associated with native copper and silver. The frequent occurrence of specular iron ore in

* See Phillips, *Treatise on Ore Deposits*, p. 175.

the crevices of lavas is probably due to the decomposition of ferric chloride by steam, thus

$$Fe_2Cl_6+3H_2O=Fe_2O_3+6HCl.$$

*General Remarks on Ores.*—With the exception of natural tellurides of gold and silver, gold always occurs in the native state. It generally contains about 8 per cent. of silver, becoming paler in colour as the proportion of silver increases. It is found intimately associated with many metallic sulphides, and is nearly always present in iron pyrites, by the oxidation and solution of

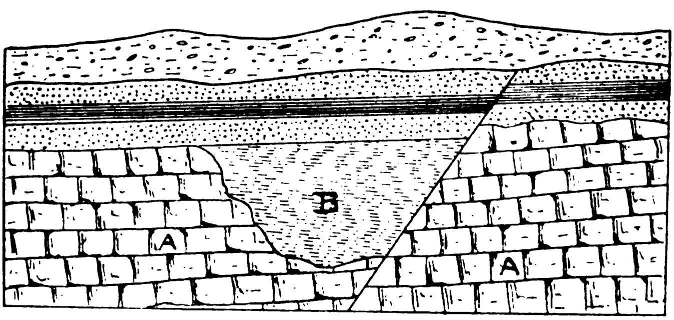


FIG. 71.—HÆMATITE DEPOSIT IN CARBONIFEROUS LIMESTONE.
A, Carboniferous Limestone; B, Hæmatite.

which it has often been liberated in placer deposits. Other geological peculiarities are its universal association with quartz and the marked connection between auriferous veins and eruptive rocks.

The chief feature in platinum deposits is their apparent connection with serpentine rocks. Up to the present time this metal has been obtained only from placer deposits, in which it occurs in the native state. Native platinum, however, is not pure, but usually contains small quantities of iridium, osmium, and palladium, as well as chrome iron, a typical constituent of serpentine rocks.

Although native silver is not uncommon, the affinity of this metal for sulphur and the halogens is so great that it is not surprising that it occurs chiefly in combination with these elements. More or less silver is always present in galena and copper pyrites, and from these a large amount of silver is extracted. Of the true silver ores, the sulphides are the most important, often associated with arsenic or antimony. Near the surface, however, the haloid silver compounds occur as products of decomposition of silver-bearing lodes.

The only ore of tin is the oxide, cassiterite, which has a well-marked geological association with igneous rocks of the acid type, containing white mica. In tin lodes, the universal occurrence of fluorine-bearing minerals is remarkable, and has led to the conclusion that tin-stone deposits have originated chiefly from decomposition of the fluoride. The weight and indestructibility of tin-stone have resulted in the accumulation of much of the ore in placers.

Copper ores easily decompose under the oxidising influence of the atmosphere. In the deeper and unaltered parts of a copper lode, sulphides are usually found, copper pyrites, or chalcopyrite, being the most common, but generally accompanied by other sulphides, such as purple copper ore and copper glance in greater or less quantity. Nearer the surface these sulphides are replaced by carbonates, the green and blue varieties of which are known by the names of malachite and azurite respectively. Finally, in the most decomposed parts of the lode only the black oxides of copper, cuprite and melaconite are found. Native copper is also common, being probably a result of the reduction of the sulphide. Geologically, copper occurs under very varied conditions. Sometimes it is found impregnating stratified beds, as at Mansfeld; at other times it exists in true fissure lodes or in contact deposits near basic eruptive rocks, or serpentine.

Galena, or sulphide of lead, is the principal ore of lead occurring at a depth below the surface. Nearer the outcrop this ore is often replaced by lead carbonate (cerussite), or the sulphate (anglesite) and other oxidised ores. Galena is very frequently associated with zinc blende, or sulphide of zinc, known to miners as "black-jack." Lead ores are usually mined rather on account of the silver which they contain than for the lead. Lodes containing argentiferous galena and blende are typically found exhibiting the banded structure already described (Fig. 61).

Practically, the only ore of mercury is the sulphide, cinnabar, which occurs in veins as well as in stratified rocks, such as slates and limestones. Occasionally it is reduced to the metallic state of quicksilver. The occurrence of this mineral in the process of deposition from hot springs at Sulphur Bank has already been mentioned, and it appears in most cases to be connected with regions of comparatively recent volcanic activity.

The following list of metallic ores is given for convenience of reference; it includes only the more commonly occurring minerals which have been mentioned in the foregoing brief outline :—

COMMON ORES OCCURRING IN MINERAL VEINS.

| Name. | Composition. | Remarks. |
|---|---|---|
| *(Silver).* | | |
| Argentite .. | Sulphide of silver .. .. | Called also silver glance |
| Stromeyerine | Cupriferous sulphide of silver.. | Black streak; lead-grey colour |
| Pyrargyrite... | Sulphide of silver and antimony | Ruby silver ores; red streak |
| Proustite .. | ,, ,, arsenic.. | Ruby silver ores; red streak |
| Horn Silver.. | Silver chloride .. .. .. | Surface ore; waxy |
| *(Lead.)* | | |
| Galena .... | Sulphide of lead.. .. .. | Often argentiferous |
| Cerussite .. | Carbonate of lead .. .. | Surface ores |
| Anglesite .. | Sulphate of lead .. .. | Surface ores |
| *(Mercury).* | | |

COMMON ORES OCCURRING IN MINERAL VEINS *(continued)*.

| Name. | Composition. | Remarks. | |
|---|---|---|---|
| Cinnabar .. | Sulphide of mercury .. .. | Volatile; red streak | |
| *(Copper).* | | | |
| Chalcopyrite | Sulphide of copper and iron .. | Yellow, often iridescent | |
| Bornite or Erubescite | Sulphide of copper and iron .. | Purple copper ore | |
| Redruthite or copper glance | Sulphide of copper .. .. | Black | |
| Malachite .. | Copper carbonate .. .. | Green | Surface ores |
| Azurite .... | „ „ .. .. | Blue | |
| Malaconite.. | Copper oxide .. .. .. | Black streak | |
| Cuprite .... | „ „ .. .. .. | Red-brown „ | |
| *(Tin).* | | | |
| Cassiterite .. | Tin oxide .. .. .. | Specific gravity = 7 | |
| *(Zinc).* | | | |
| Blende .... | Zinc sulphide .. .. .. | Often argentiferous | |
| Calamine .. | Zinc carbonate .. .. .. | Surface ore | |

The ores of iron, manganese and aluminium have already been given in Chapter V., Part I.

## CHAPTER VII.

*Non-Metalliferous Minerals—Carbon Minerals—Phosphate Deposits—Products of Solfataric Action—Saline Deposits—Cobalt Ores—Segregation Products.*

*Non-Metalliferous Minerals.*—The distinction between an earthly mineral and an ore is not very clear, for many minerals which are now comparatively neglected may, with improved metallurgical processes, become important sources of metal. The ever-varying demands of the arts and manufactures, also, are constantly bringing new mineral species into requisition, and as constantly are causing others to sink into insignificance from an economic point of view. This consideration makes it still more necessary for all who are engaged in quarrying or mining to keep continually in view the modern developments of manufacturing industries, in order to derive the utmost profit from the raw materials hidden in the earth. A simple illustration of the truth of this remark is afforded by the alum clay (bauxite) and alum shale industries, the former having recently sprung into importance as an ore of aluminium, and the latter as a source of alum, having now almost ceased to be of any commercial value. The cobalt ores also promise to be in greatly increased demand, in consequence of the recently discovered superiority of this metal to nickel for purposes of electro-plating. Of the very large number of minerals of economic interest, the following have been selected for a detailed description in the present chapter as being those which are chiefly in demand, as well as furnishing the most instructive examples of the geological conditions under which they may be expected to occur.

*Carbon Minerals:* (1) *Peat.*—All the minerals of this

group may be looked upon as products of the alteration of vegetable matter, by which process a regular gradation may be traced from peat through coal to graphite. Peat bogs are found chiefly in the temperate parts of the northern hemisphere, where they occupy boggy marshes, silted up lakes, or the sites of water-logged forests. The preservation and growth of peat mosses are due to the slowness of decay below water level, assisted by the antiseptic properties of organic acids derived from the vegetable matter. Drainage effectually stops its growth. In the British Isles alone several millions of acres are covered by peat deposits, ranging in depth from five to thirty feet. The Bog of Allen, in Ireland, covers an area of 238,500 acres, and the Great Dismal Swamp of Virginia covers nearly 1,000 square miles, having a depth of 15 feet of pure vegetable matter. After heavy rains, a peat bog sometimes swells up and bursts, inundating the surrounding country with a black ooze, or vegetable mud, of macerated organic matter of a similar nature to that from which some cannel coals appear to have been formed.

As a fuel, peat is deficient in carbon. The main obstacle to its preparation is the difficulty of drying it in an uncertain climate. Raw peat contains 75 per cent. of water, which by air drying can seldom be reduced below 25 per cent. Several schemes have been tried for pulping, drying, and compressing peat, either alone, or with coal slack, tar, or paraffin, into briquettes, to which increased attention will doubtless be given as we approach nearer to the limit of our coal supply.

(2) *Lignite, or Brown Coal.*—In this substance we see a further stage of the alteration of woody matter. Lignite deposits are usually found beneath a varying thickness of gravel, sand, or clay, and are probably due to the accumulation of drift wood in pools or river bends. The mode of occurrence of lignite is shown in Fig. 72.

In the Rhine Valley, beds of lignite, often more than 50 feet thick, are regularly made into briquettes, the deposit being easily worked with pick and shovel. In the operations of drying and compressing, care has to be taken not to remove the whole of the water, of which 18 per cent. should be left, to prevent carbonisation of the resins of the wood by the heat of compression. Both peat and lignite often contain sufficient bituminous matter to yield paraffin and other oils, as well as tar, on

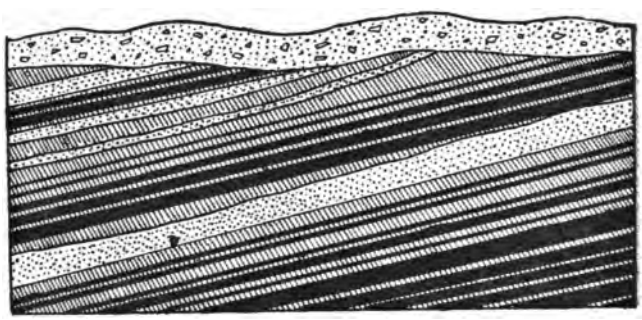

FIG. 72.—SEAMS OF LIGNITE, INTERSTRATIFIED WITH CLAYS AND SANDS, BOVEY TRACEY, DEVON.

distillation, the "Bovey" coal of Devonshire and the peat of Kildare having been extensively used for this purpose. Any diminution in the existing supply of petroleum would again direct attention to these sources of natural oils. The pitchy lignite of Arkansas yields 68 gallons of oil, and a large quantity of solid paraffin per ton. The objections to the use of lignite as fuel are the difficulty of drying, the tendency to crumble, the offensive odour and excess of smoke when burnt, with a larger quantity of earthy ash and a smaller amount of heat than coal. In texture, lignites vary from compact, woody varieties, known as "wood coal," to

finely laminated "paper coal," and soft, earthy "peat coal." The seams are uncertain to work, thinning out rapidly and much intercalated with sands and clays.

*Jet*, a compact lignite, occurs in detached masses in the alum shales of Whitby (Upper Lias), as well as in alluvial deposits in Syria, Spain, and Russia; while

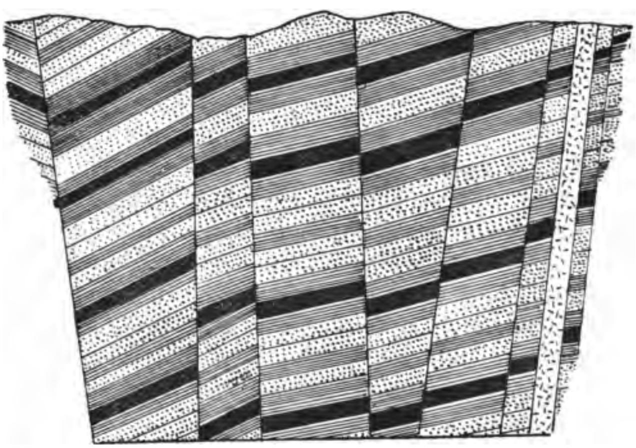

FIG. 73.—FAULTED COAL SEAMS IN THE SANDSTONES AND SHALES OF THE COAL MEASURES.
Dotted shading represents Sandstones; Parallel lines, Shales and Under-clay (Fire-clay).

*amber*, a fossilised pine resin, is found under somewhat similar conditions in the Tertiary clays of the Baltic, France, and Austria.

(3) *Coal*.—In the alteration of vegetable matter there is a gradual loss of the more volatile constituents, with a corresponding increase in the proportion of carbon, thus giving rise to cannel coals, bituminous coals, or anthracite, which, however, graduate imperceptibly into one another. These different kinds of coal are, indeed,

frequently found very irregularly distributed within the area of even a single coal field, a result which is partly due to variations in the original composition of the vegetable débris, and partly to the different degrees of alteration which it has undergone. Some coal seams, and especially those of Tertiary age, may be merely altered peat (*peat bog theory*); but the carboniferous coal seams are so interstratified with marine sediments (see Fig. 73) that they are probably due to estuarine accumulations (*drift theory*), or to forest growths in coastal swamps and lagoons (*growth in situ theory*). The prevalent idea that true coal is a product of carboniferous rocks alone is erroneous, workable coal having been discovered in rocks of many of the later periods. Many of these younger coals, although at the present time not worked to a large extent, will increase in importance in future years. Of this nature are the immense supplies of Cretaceous and Tertiary coal of Texas and the Rocky Mountains, and the Jurassic and Cretaceous coals of India, Australia and New Zealand. Even in the British Isles Oolitic coal has been worked in Yorkshire and at Brora in Sutherland.

Nearly all coal seams are found to be built up of parallel laminations of bright, lustrous pitch coal, separated by layers of powdery charcoal. The character of the coal depends upon the thickness and composition of these laminations, which are very variable. An asphaltic variety of cannel, called *albertite*, has been found in New Brunswick, under somewhat peculiar conditions. It forms an almost vertical vein in highly bituminous rocks, and yields an abundance of oil. A similar seam, thin, but of excellent quality, has been found in Sutherland, near the junction of the Old Red Sandstone with metamorphic schists.

(4) *Solid and Liquid Hydrocarbons.*—The slow decomposition of carbonaceous deposits has led to the

VARIETIES OF COAL.

| Variety. | Calorific Power in Calories. | Percentage Composition. | | | Coke. | Appearance. | Uses. |
|---|---|---|---|---|---|---|---|
| | | Carbon. | Hydrogen. | Oxygen and Nitrogen. | | | |
| Peat .. .. | 3000 | 53 | 5 | 32 | nil | fibrous | kilns and domestic heating. |
| Lignite .. .. | 5000 | 60 | 5 | 35 | nil | | domestic heating. |
| Australian Shale, Bog-head Cannel, Wigan Cannel | 6000 | 70 | 9 | 5 | poor | brown to black; compact, conchoidal fracture | gas making. |
| Splint Coal .. | 8000 | 80 | 5 | 19 | powdery | hard, conchoidal fracture | gas making & domestic use. |
| Caking Coal .. | 8500 | 85 | 6 | 14 | friable | tough, black, shining | gas making & domestic use. |
| Furnace Coal .. | 8800 | 90 | 5 | 10 | dense | very black and shining | coking and smithy use. |
| Anthracite .. | 9000 | 92 | 3 | 3 | powdery | hard, brittle | smokeless, steam coal. |

accumulation of natural oils and gases in many rocks, as well as in the impregnation of shales and sandstones with bituminous matter, and the deposition of solid and liquid hydrocarbons of considerable economic value. Bituminous shales, from which oil can be distilled, occur in many rocks unassociated with coal seams, and are evidently old estuarine muds charged with organic matter. In Sweden an interesting deposit occurs in highly metamorphosed gneissic rocks of Laurentian age. In the British Isles several valuable beds of bituminous shale occur, amongst which the celebrated "Bog Head Cannel" of Torbane Hill, Linlithgow, has been extensively worked. On the banks of the Rhone Jurassic limestone, impregnated with bitumen, is quarried in blocks for the manufacture of asphalte, a richer deposit of the same age being worked in the Val de Travers. Of similar origin are *hatchettine*, a mineral tallow found in nodules of clay ironstone in the South Wales coal field; *ozokerite*, a mineral wax imported from Moldavia for the manufacture of candles; and *elaterite*, an elastic bitumen found in the carboniferous limestone of Derbyshire. The celebrated Pitch Lake of Trinidad is an outflow of thick bituminous matter issuing from the hillside, and hardening by oxidation on exposure to the air.

Borings sunk for water have often tapped bituminous strata impregnated with petroleum and natural gas. Such oil wells are common in the Permian sandstones of Hanover, and in the Miocene strata of Southern Europe, the Caucasus, and the valleys of the Euphrates and Irawadi. As the existing sources of supply of petroleum and natural gas must ultimately fail in the absence of any natural replenishing process, the value of deposits now neglected must tend to improve. Fig. 74 represents in section one of the oil fields of Pennsylvania, which present some interesting features bearing upon the geo-

logical relations of petroleum. These oil supplies are subterranean pools which have collected in porous reservoirs of sandstones or limestone, bounded above and below by impervious strata. The beds have been thrown

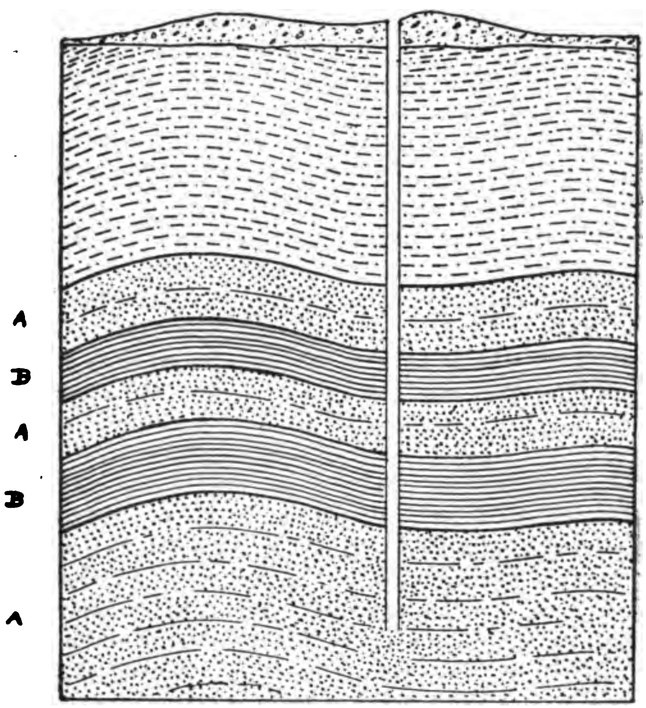


FIG. 74.—OIL WELL IN PENNSYLVANIA
A, Oil-bearing Sandstones, Middle Devonian; B, Shales.

into slight folds, and the oil shows a marked tendency to collect in the axes of the anticlinals, causing a general parallelism of the oil fields with the axes of the Appalachian folds. The oil is usually accompanied by a quantity of marsh gas and brine, the last-named usually

heralding the approaching failure of the supply. In all cases the source of the oil is a neighbouring deposit of decomposing organic matter, either of land plants, seaweed or fish. In the Eastern States the oils occur in Palæozoic strata from the Silurian upwards, the chief deposits occurring in the Trenton limestone of the Silurian; but in Colorado the Laramie shales of the Cretaceous are oil bearing, and there are Tertiary oil bearing beds in California.

(5) *Graphite and Diamond.*—The final product of the slow transformation of organic matter is pure carbon. Graphite often occurs in flakes and grains in metamorphosed rocks, and in nests and veins in some granites and porphyries. The actual transformation from anthracite to graphite may perhaps be represented by the graphitic anthracite of Rhode Island, while at New Cummock, in Ayrshire, coal may be seen altered into graphite in the proximity of a sheet of basaltic rock. All workable graphite deposits occur in seams and veins in metamorphic or igneous rocks, the largest supplies coming from Ceylon and Siberia. The famous Borrowdale graphite of Cumberland, now practically exhausted, occurs in trap rocks interbedded with Silurian slates. The origin of diamond, the naturally crystallised form of carbon, is still obscure, but its connection with graphite may be traced through the dark-coloured *carbonado*, and the impure varieties called *bort*. The earliest discoveries of the diamond were in alluvial gravels and detrital conglomerates in India, where, from its unalterability by ordinary meteoric agencies, it would be expected to occur. In Brazil the parent rock appears to be itacolumite, a schistose quartzite in which the granules are separated by scales of mica, talc, chlorite and sericite, giving flexibility to the rock. From the flexible sandstone a ferruginous sand, called *cascalho*, in which diamonds are found, is derived.

In South Africa, great interest attaches to the discovery of diamonds in volcanic necks of serpentinised olivine-diabase, much brecciated, as represented in the diagram, Fig. 75. A number of these necks occur within a small area, representing the central pipes of a cluster of extinct volcanoes (Fig. 76), and now forming the valuable collection of diamond mines worked by the De Beers Company.

1
2
3
4

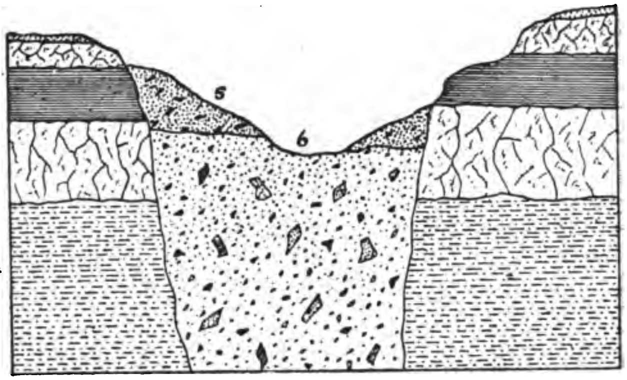


FIG. 75.—DIAMONDS IN VOLCANIC NECK, DE BEERS MINES, SOUTH AFRICA.

1, Basalt; 2, Shale; 3, Melaphyre; 4, Quartz-rock; 5, Upper decomposed part of volcanic neck (yellow ground); 6, Blue ground (unweathered), containing fragments of Olivine Rock, Basalt and Shale, with Diamonds and other Minerals.

*Phosphate Deposits.*—Phosphate of lime exists in great quantity in almost every variety of rock. In the form of the mineral *apatite*, it is disseminated in grains and crystals in the crystalline rocks, and is often found concentrated in veins and lodes. In Canada large quantities are mined in Laurentian limestones and gneiss, and it occurs under similar conditions in the neighbourhood of Arendal, Norway. Such deposits as these may be looked upon as original constituents of the rocks, and the

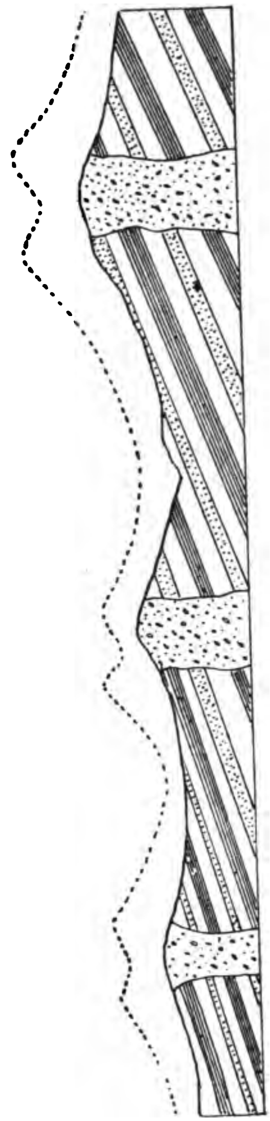

FIG. 76.—VOLCANIC NECKS IN WHICH THE DE BEERS MINES ARE SITUATED (Diagrammatic section).
Dotted lines suggest outline of former Volcanoes.

source of most of the phosphate of lime used by the animal kingdom. Nearly all the later phosphate accumulations are the result of bone beds and guano deposits, similar to the well-known recent deposits of the Chincha Islands, Tarapaca and Sombrero. Such accumulations can only occur where climatic conditions are favourable, a circumstance which explains the inferiority of African guano, from which a large part of the more soluble ammoniacal salts are washed out. Not only the excrement of birds, but also the bones of animals, are a frequent source of mineral phosphate. The rich deposits of Carolina and Florida, represented in Fig. 77,

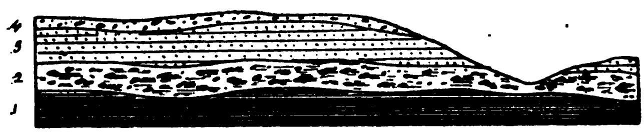


FIG. 77.—CAROLINA PHOSPHATE BED.
1, Eocene Marl; 2, Phosphate bed; 3, Sand; 4, Surface soil.

are evidently an old bone bed accumulated in shallow coastal waters, under somewhat similar conditions to the remarkable collection of bones formed at the Big Bone Salt Lick of Kentucky from the remains of mammals in search of salt. These phosphate beds have often undergone a considerable amount of chemical transformation in the shape of solution and redeposition, in the form of nodular concretions or *coprolites*. The various forms under which phosphate deposits have been worked may be conveniently summarised in the following table:—

PHOSPHATE DEPOSITS.

| *Mode of Occurrence.* | *Typical Localities.* |
|---|---|
| 1. Pockets and bunches in crystalline rocks. | Laurentian gneiss of Canada. Gneiss of Arendal, Norway. |

| | |
|---|---|
| 2. Beds in Stratified Rocks | Cambro-Silurian Strata of the Berwyns (see Fig. 78.) Recent beds, such as Guano of Peru, and Osite or Sombrerite of West Indies (a phosphatic coral limestone mixed with guano.) |
| 3. Nodular concretions (coprolites. | Greensand of Cambridge, the Ardennes, the Meuse and Nassau. Carolina and Florida phosphate beds (Tertiary). Bordeaux phosphates (Eocene.) |
| 4. Granules in Chalk or Limestone. | Phosphatic Chalk of Ciply, Mons and Taplow. |

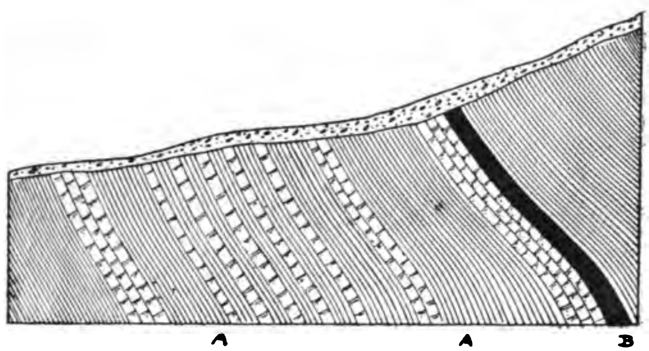


FIG. 78.—PHOSPHORITE BED IN THE BERWYN MOUNTAINS.
A, Bala series, Limestones and Shales; B, Phosphorite bed.

The comparatively recent discovery of phosphatic chalk, both in Belgium and England, is of exceptional interest, as pointing to the possibility that still more extensive beds may yet be found. In Figs. 79, 80, adapted from M. Cornet's paper,* the position of the phosphate bed is shown, rich pockets being occasionally produced by solution of the accompanying chalk.

The value of phosphates for agricultural purposes depends upon the completeness with which they can be transformed into soluble superphosphate by the action

* Quarterly Journal of the Geological Society, vol. xlii., p. 332.

of sulphuric acid. If the phosphate contain much calcium carbonate, a great deal of the acid is neutralised, and, moreover, the presence of oxides of iron and alumina tends to reconvert the superphosphate into the insoluble state. These considerations, therefore, materially influence the commercial value of mineral phosphates.

*Products of Solfataric Action.*—The preceding groups of minerals have originated from the decay of animal or vegetable matter. We now proceed to the consideration

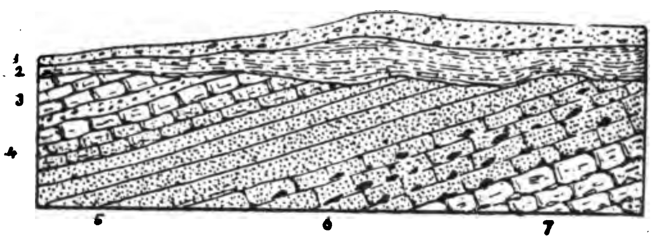


FIG. 79.—PHOSPHATIC CHALK OF MONS.
1, Gravel and Loam; 2, Tertiary Sands and Clays; 3, Tufaceous Chalk; 4, 5, 6, Phosphatic Chalk, Flints being absent in 5; 7, Chalk with Flints.

of quite a different class of substances, beginning with the results of volcanic exhalations, such as sulphur and boracic acid.

Sicilian sulphur occurs in nests and veins in miocene clays, where it is associated with gypsum, carbonate of lime and sometimes barytes. At Naples, and also in Iceland, sulphur is deposited from exhalations of sulphur vapours, or solfataras. Sulphur is also formed as a decomposition product of metallic sulphides, notably iron pyrites, which is also largely used as an artificial source of this substance. The large quantity of sulphur produced from this source, and from alkali waste, is causing the demand for native sulphur to diminish. In

fact deposits of this mineral are almost valueless unless favourably situated for transport. In connection with the natural production of sulphur, some interesting chemical reactions, which have some practical importance, may be mentioned.

Whenever water containing sulphates in solution comes into contact with organic matter, sulphuretted hydrogen gas is produced, an example of which is afforded by the accumulations of this gas, noticeable in

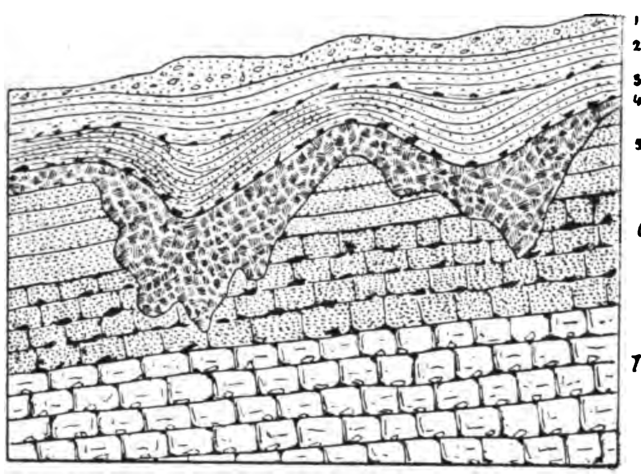


FIG. 80.—PHOSPHATIC CHALK OF MONS.
1, 2, 3, Post-tertiary Sands and Brick-earth; 4, Pockets of rich Phosphate; 5, 6, Phosphatic Chalk; 7, White Chalk with Flints.

many abandoned coal mines into which gypseous waters have penetrated. The reduction of gypsum by organic matter may be chemically represented thus:—

$$\underset{\text{Gypsum}}{Ca\,SO_4} + 2\,C = \underset{\text{calcium sulphide}}{Ca\,S} + \underset{\text{carbonic acid.}}{2\,CO_2}$$

The calcium sulphide is then decomposed by carbonic acid as follows:—

$$\underset{\text{Calcium sulphide}}{CaS} + CO_2 + H_2O = \underset{\text{calcium carbonate}}{Ca\,CO_3} + \underset{\text{sulphuretted hydrogen.}}{H_2\,S}$$

Now sulphuretted hydrogen, on oxidation by the atmosphere, is partly decomposed, with a deposit of sulphur, and partly oxidised to sulphuric acid. In contact with limestone rocks, also, sulphuretted hydrogen forms gypsum and deposits sulphur, a reaction to be seen in actual progress in the blistering of the limestone walls of the sulphurous springs of Aix. By such reactions as these, the presence of sulphuretted hydrogen in many mineral springs, as well as the frequent association of gypsum and sulphur, is easily explained.

Another product of volcanic exhalations is boracic acid, collected commercially from the hot vapours issuing from the fumaroles of Tuscany. Chemical works have been established in the crater of Volcano, in the Lipari

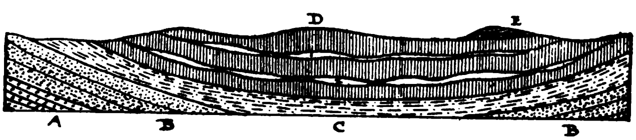


FIG. 81.—ROCK-SALT IN KEUPER MARLS OF CHESHIRE.
A, Bunter Sandstone; B, Freestones; C, Flagstones; D, Keuper Marls; E, Dutlier of Lias.

Isles, for the purpose of collecting the vapours of sal-ammoniac, sulphur, and boracic acid, which issue from the fissures. In California, borax occurs in fissure veins, probably infiltrated by hot springs, similar to those of Tuscany. It is possible that boracic acid may be formed from the decomposition of boracite (magnesium borate), a mineral sometimes found associated with gypsum.

*Saline Deposits.*—The evaporation of salt lakes, such as the Great Salt Lake, Utah, has been a repeatedly occurring phenomenon in almost every period of the earth's history. The resulting beds of rock salt and gypsum are now the scene of important industries in many parts of the world. The accompanying section (Fig. 81), across the New Red

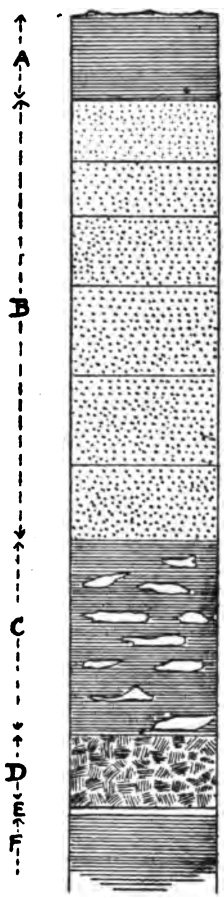


FIG. 82.—ROCK-SALT AND GYPSUM AT MIDDLESBOROUGH.

A, Alluvial; B, Triassic Sandstone; C, Marls with Gypsum and Anhydrite; D, Rock-salt, 100 feet; E, Anhydrite; F, Saliferous Marl.

Sandstone Plain of Cheshire, shows the position of the two beds of rock salt, from which the brine springs issue. Each bed is more than 90 feet thick, and is made up of irregular masses of rock salt, tinged reddish with ferric oxide, and associated with gypsum. This bed is mined in Cheshire and parts of Lancashire and Staffordshire, as well as at Carrickfergus, in Ireland, while brine is pumped from the same strata in Cheshire, Worcestershire, and near Middlesborough (Fig. 82). In Spain, at Cardona (Catalonia), the river cuts through a bed of rock salt 120 feet thick, which is strikingly exposed in the cliffs of red sandstone and marl. At a slightly lower stratigraphical level, in the Zeckstein group of Saxony, a remarkable bed of rock salt, with thin seams of gypsum, has been bored to a depth of 685 feet at Stassfurt, and nearly 5,000 feet at Sperenberg, near Berlin. Fig. 83 represents the mode of occurrence of this deposit, as well as the position of the associated beds of potassium chloride (sylvine). It would occupy too much space to detail here the very numerous rock salt beds of the world, but passing mention

must be made of the Triassic deposits of the Austrian Tyrol at Salzberg, the remarkably thick beds mined in huge subterranean caverns at Wieliczka, near Cracow, in Tertiary marls, and the Eocene mountains of rock salt at Bahadur Khel in the Punjab,

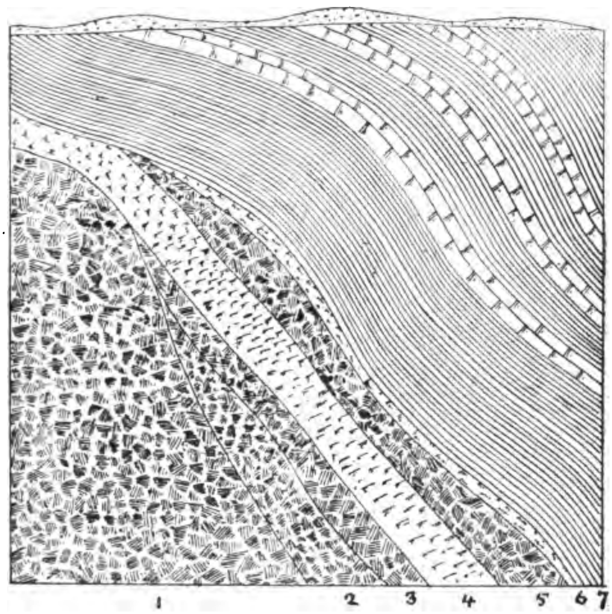


FIG. 83.—ROCK-SALT AND GYPSUM OF STASSFURT.
1, Rock-salt; 2, 3, Rock-salt with Sylvine and Kieserite; 4, Gypsum; 5, Rock-salt; 6, Gypsum; 7, Bunter beds.

where the salt is quarried at the surface by the ordinary tools and blasting powder.

In all such deposits the less soluble salts will generally be first deposited. Gypsum is, therefore, more usually abundant in the lower parts of the bed, while the more soluble chlorides of magnesium are seldom present at all.

Gypsum is a hydrous sulphate of lime. There is also an anhydrous sulphate, called *anhydrite*, which frequently accompanies the hydrated form. Anhydrite readily becomes hydrated, when it not only expands in volume, but also produces upheavals in the overlying beds, and is a cause of the loosening of the walls of mines. This natural transformation of anhydrite into gypsum is of the same nature as the familiar process of the setting of plaster of Paris. In some cases gypsum has evidently resulted from the alteration of limestone by the action of sulphuric acid (derived from the decomposition and oxidation of pyrites) and soluble sulphates.

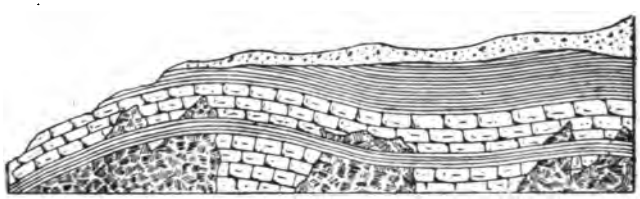

FIG. 84.—MASSES OF GYPSUM, INTERSECTED BY SEAMS OF CLAY, IN LIMESTONE OF SALINA GROUP OF ONONDAGA.

Fig. 84 is an example of this transformation in the limestone of the Salina Group of Onondaga. Fig. 85 shows seams of gypsum in the Triassic sandstones of Somerset, evidently deposited subsequently to the enclosing rock. The regular beds of gypsum in the gypseous marls of the Paris basin have been ascribed to the action of sulphurous waters upon a lake charged with calcareous salts. The crystalline form of gypsum, called *selenite*, is an abundant product in many clays. Among other deposits from saline waters may be mentioned *tincal*, a crude borax found in the lakes of Thibet, and in the dried-up lakes of the desert region of Nevada and California; borate of calcium (*tiza*), scattered over the plains of Iquique; nitrate of soda (*Chili saltpetre*), found

in layers 8 in. thick, beneath beds of salt, on the desert of Atacama; *natron*, a natural carbonate of soda, found in many Egyptian lakes, a variety called *trona*, occurring beneath the soil in Tripoli; and, lastly, *nitre*, formed in the soil of India by the action of nitrogenous waste upon wood ashes in the neighbourhood of the villages.

*Cobalt Ores.*—A brief notice of some of the sources of cobalt may be useful in directing attention to the increasing importance of this metal. In addition to *smaltine* and *cobalt bloom* (*erythrite*), compounds of cobalt

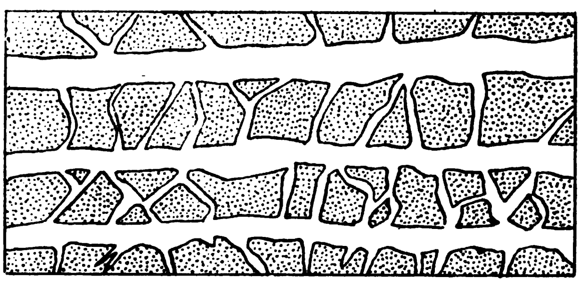

FIG. 85.—GYPSUM IN TRIASSIC SANDSTONES.
Seams connected by cross veins (de la Beche).

and arsenic, there is an earthy black oxide known as *asbolane*, which has been found in cavities of carboniferous limestone near Rhyl, in North Wales, as shown in Fig. 86, associated with clay and nodules of hæmatite and manganese. Smaltite and erythrite are often associated with copper ores, and an interesting example of its occurrence near the hanging wall of an igneous dyke is given in Fig. 87, while in Fig. 88 we have an illustration of kernels of cobaltiferous oxide of manganese found in the purple slates of Rio Tinto.

*Segregation Products.*—The intricate chemical changes which are continually taking place in all rocks, owing

mainly to the percolation of water, lead to the development of many secondary minerals in cracks and hollow cavities. Silica in various forms is very commonly found in this way, not only in the form of quartz veins, but also in various crystalline forms, which, when coloured by impurities, or enclosing other mineral species,

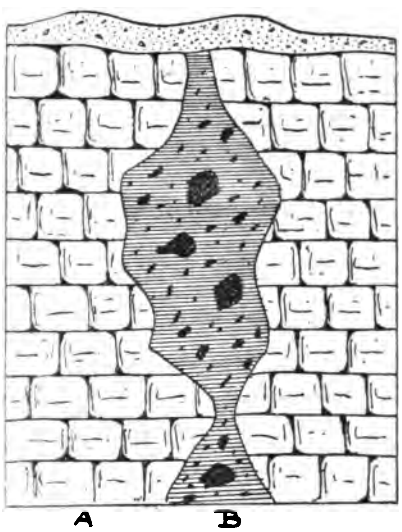


FIG. 86.—COBALT ORE IN LIMESTONE, RHYL.
A, Carboniferous Limestone; B, Pocket of Clay with nodules of Asbolane.

become valuable as gems. In the quarrying of rocks, therefore, the contents of all such drusy cavities, or *geodes*, should be carefully examined. In cavities of this nature, valuable gems have been found. *Topaz* and *beryl* occur in hollow cavities in the granite of the Mourne Mountains; *ruby* and *sapphire* are found in the serpentine of Corundum Hill, North Carolina; *turquoise* is associated with an intrusive trachyte in New Mexico; while

*opal* occurs in amygdaloidal cavities in the basalt of Washington. More complete details of these minerals will be given later, the following chapter being given to

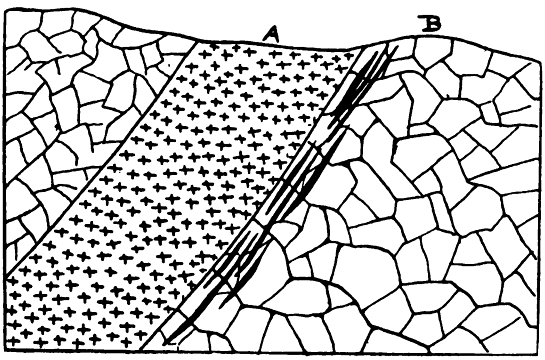


FIG. 87.—STRINGS OF COBALT ORE IN THE NEIGHBOURHOOD OF A DYKE, TRANSVAAL.
A, Dyke of Dolerite; B, Fine-grained Felsite, with strings of Ore.

the practical recognition, with which every quarryman should be familar, of the signs which guide the prospector in his search for valuable products.

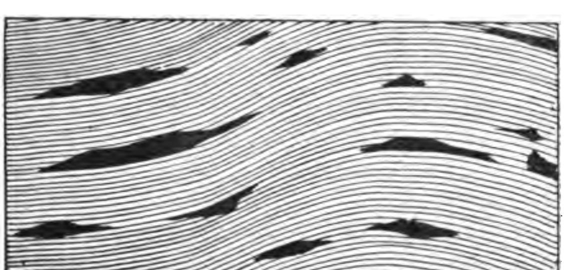

FIG. 88.—KERNELS OF COBALT ORE IN SLATE.

## CHAPTER VIII.

*Prospecting and Developing—Recognition of Minerals—Examination of Detrital Deposits—Gossan—Association of Minerals—Quarries or Open Works—Bed-mining—Vein-mining.*

*Prospecting and Developing.*—We have now seen under what geological conditions the more important minerals occur. Before leaving this part of the subject, however, we have still to consider how far the presence of these minerals may be predicted, and how far geological knowledge may assist in their exploitation when found. Accidental discoveries will of course always be made, and in the course of extracting one mineral the unsuspected existence of another may be established. There are many classical examples of such accidents. The great Wallaroo copper lode was discovered by the green earth thrown out by a wombat; South African diamonds were originally collected in pure ignorance of their nature and value by Dutch farmers; the porous auriferous stone of Mount Morgan was abundantly sold as hearthstone; the Comstock lode was first worked for gold, the black sulphide of silver, which has yielded untold wealth, being then discarded as valueless; chance analyses of soil led to the discovery of the rich phosphate deposits both of Florida and N. France; and Californian gold was first noticed as glittering specks in a mill leat. It is more than probable that a large number of valuable products are still neglected through ignorance of their real character. The quarryman in limestone rocks, for instance, may hit upon an apparently worthless pocket of clay, in which further examination might reveal the presence of workable deposits of asbolane, manganese, or hæmatite. The conditions under which minerals occur are so varied that there is practically no kind of

rock, from the most ancient to the most recent, which may not enclose mineral treasures of the greatest value.

On the other hand, it does not necessarily follow that a mineral deposit, when discovered, will pay for working. Enormous sums have been wasted in the attempt to develop mineral deposits which occur under such geological conditions that success is impossible; while, in other cases, works have been abandoned when obstacles have been encountered which a little geological knowledge would have easily overcome. The proverbial uncertainty of mining or quarrying, as well as the elements of chance in mineral discoveries, may both be materially reduced by a knowledge of the ascertained laws which govern the mineral kingdom.

The history of the course of events leading to the development of many of the richest mineral deposits of the world affords an instructive lesson in the value of scientific prospecting. Let us briefly examine a single instance—the growth of the important tin mining industry of New South Wales.* More than thirty years ago fragments of cassiterite were recognised in the black sands of the Australian gold fields, suggesting the occurrence of tin ore in the numerous granite bosses near the Queensland boundary of New South Wales, where, as in Cornwall and the Erzgebirge, the granite was intrusive in clay slates. Later, *unworn* crystals of cassiterite were found in the decomposed granite of the surface of these bosses, conclusively pointing to the underlying granite as their source. In 1872, the gravels of the streams issuing from this granite district were washed with such good results that tin stream-works upon a large scale rapidly developed. The rapid exhaustion of these shallow, recent, and pleistocene gravels soon followed; but a coating of Tertiary basalt, being suspected to cover

* Phillips. Ore Deposits, p. 663.

up still older alluvial deposits, was then penetrated, and the deep leads of Vegetable Creek soon proved to be remarkably rich deposits of tin-bearing gravel. Then followed the exploitation of the stanniferous granite itself, in which lode tin, in veins, impregnations, and stockworks, is now extensively worked. Thus lode mining has been the natural outcome of the discovery of alluvial tin. The first work of a prospector in any district, therefore, will be to take advantage of the natural processes of disintegration which have led to the accumulation of the results of ages of denudation in the sands and gravels of the river courses.

*Recognition of Minerals.*—The prospector has usually to rely upon the simplest tests for the identification of the minerals which he finds. Nothing more than an outline can be attempted here of the methods to be adopted, but a more complete scheme will be afterwards given (see Appendix). The following points should, however, be carefully noted :

1. *Structure*, which may be granular (as *chrome iron*), saccharoid (*alabaster*), lamellar (*talc*), capillary (*asbestos*), fibrous (*satin spar*), radiate (*pyrites*), bacillary (*epidote*), dendritic (*manganese oxide*), concretionary (*iron ore*), mamillary (*hæmatite*), or vitreous (*amber*).
2. *Crystalline form*, which may often be obscured, and is generally absent in water-worn specimens.
3. *Cleavage*, which may be perfect (as in *calc-spar*), imperfect (*cassiterite*), or absent altogether (*quartz*).
4. *Lustre*, which may be metallic (as in *pyrites*), semi-metallic (*hauerite*), adamantine (*diamond*), vitreous (*calcite*), resinous (*blende*), pearly (*talc*), silky (*satin-spar*). Nearly all metallic sulphides have a metallic lustre, except zinc blende and cinnabar.
5. *Colour*. Both lustre and colour are often invisible in a water-worn or altered specimen. Colour may also be influenced by the presence of impurities.

6. *Streak*, or the colour of the powder produced by crushing the specimen on a piece of white paper, or by drawing it across a slab of unglazed porcelain. In many cases the streak differs characteristically from the colour of the mineral.
7. *Hardness*, a most useful test, for which purpose the following scale, due to Mohs, is generally followed:—

| | |
|---|---|
| 1. Talc. | 6. Orthoclase. |
| 2. Rock-salt or gypsum. | 7. Quartz. |
| 3. Calcite. | 8. Topaz. |
| 4. Fluorspar. | 9. Corundum. |
| 5. Apatite. | 10. Diamond. |

In actual practice an approximation to the hardness of a mineral may be obtained by the following rough tests:—

Minerals which are not scratched by a good knife have a hardness greater than 6.

Minerals which will not scratch a bronze coin have a hardness less than 3·5.

Minerals which can be scratched by the thumbnail have a hardness less than 2·5.

Minute particles which are too small to scratch must be half imbedded in a cement of bees'-wax and resin (electric cement), and drawn over substances of known hardness, such as glass, or bronze coins. In all cases it must be remembered that decomposed minerals are usually much softer than the fresher specimens.

8. *Malleability*, *flexibility*, *smell*, and *taste* are occasionally useful tests. Thus, argentite and gold are malleable, talc is flexible, pyrites emits a sulphurous smell on friction, and soluble salts possess taste.
9. *Specific Gravity*.—A rough estimate can be made by guess work in the case of large specimens, but for accurate determinations a Walker's Balance is both simple and portable. For minute particles, and

especially in the separation of small gems from quartz and other lighter matter, recourse must be had to dense liquids, of which the following have been recommended :—

*a. Sonstadt's solution*, a saturated solution of mercuric iodide in potassium iodide, which has a density of 3·2, and which will effect the separation of diamonds from quartz sand.

*b. Rohrbach's solution* of mercuric iodide and barium iodide, which has a density of 3·5, but must not be diluted with water, which decomposes it.

*c. Klein's solution* of boro-tungstate of cadmium has about the same density as the above (3·28), and possesses other advantages over the poisonous mercury compounds. It is decomposed by carbonates, which must be first removed by weak acid.

*d.* Braun's solution of methylene iodide; specific gravity, 3·3.

*e.* Retger's solution of methylene iodide, iodoform, and iodine: specific gravity, 3·6.

*f.* Fused silver iodide and silver nitrate, which is as dense as 5·0, and would separate rutile and magnetite from cassiterite.

10. *Blowpipe characters*, the recognition of which requires some amount of skill and a knowledge of practical chemistry.

*Examination of Detrital Deposits.*—In the selection of likely sites for placer deposits, it is necessary to bear in mind the conditions which regulate the formation of gravel beds in rivers. These occur at all points where the velocity is checked, either by the widening of the channel in flood time, or in the slack water on the convex side of a sharp bend. The form of the valley, therefore, has an important influence upon the distribution of alluvial gravels. The prospector should bear in mind not only the present shape, but also the former configuration of the valley as shown by ancient terraces and high level gravels.

The case of deep leads presents still greater difficulty, since the old river beds may have no relation whatever to existing water-sheds, and are usually covered up by thick alluvial or volcanic deposits of more recent date. Unless, therefore, the bed rock crops out on each side of the overlying deposits, the exact position of the gravel

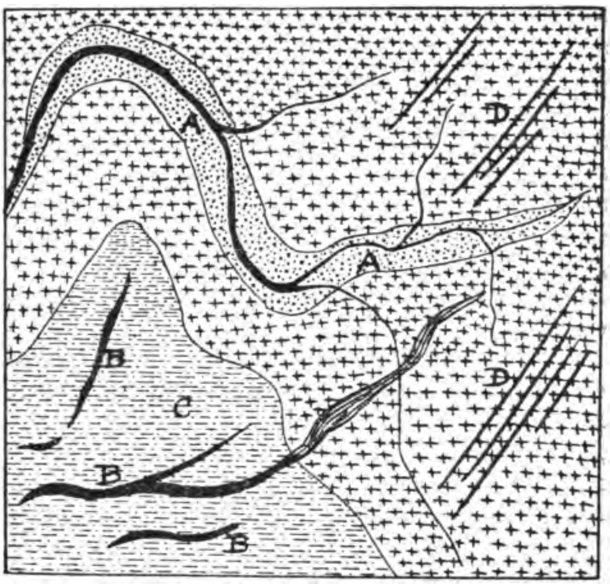


FIG. 89.—TIN DEPOSITS OF NEW SOUTH WALES.
A, Alluvial Tin; B, Deep Leads; C, Basalt covering Deep Leads; D, Tin Lodes in Granite.

patches below can only be hit upon either by accident or by extensive subterranean exploration by trial borings. Fig. 89 represents the relations of these two kinds of alluvial deposit.

In the examination of sands and gravels, recourse is had to *panning*, a process which consists in carefully washing away the lighter materials, after the larger

stones have been picked out, by swirling with water in a shallow pan until finally only the heavy particles are left behind. By this means, the heavy specks of gold, platinum, tin-stone, magnetite, and certain of the gems can be separated from the lighter earth and sand, and preserved for more detailed examination. The bottom layer of the gravel, lying immediately upon the bed-rock, is usually the richest; and all cracks and crevices in the neighbouring rocks should be carefully cleaned out and panned, since heavy particles would be naturally arrested in these inequalities of the surface. The gems, such as diamonds, sapphire, ruby, or emerald, likely to occur in river gravels, are in most cases distinguished by their excessive hardness. Gold grains are sometimes obscured by a film of sulphur or arsenic, or are in so fine a powder that recognition is not easy. Tin-stone, also, is by no means easy to identify when in amorphous, water-worn fragments.

Another method of separating small particles of heavy minerals from a loose, dry sand, such as beach sand, is to force the grains to descend an inclined cardboard plane slowly by tapping gently with the finger. The heavy particles will be found to lag behind, and to form a crescent at the top of the talus thus formed. Grains of magnetite can, of course, be readily separated by means of a magnet.

*Gossan.*—In following up a stream to its source, water-worn stones of ore, called *shodes*, are often noticed. As these must have travelled downhill, their source is evidently somewhere higher up the valley, near the point where their disappearance is noticed. This locality is, therefore, carefully searched for the outcrop of the lode from which the shodes were derived. In this the prospector may be assisted by the configuration of the ground, hard veins of quartz being often conspicuous as wall-like ridges, traceable for long distances across the

country. Far more important, however, is the invariable evidence of chemical action at the outcrop of the lode, resulting in the decomposition of the lode minerals and the production of various coloured metallic oxides, which stain the weathered outcrop, and produce hollow, cellular cavities in the quartz. Such stained and cellular quartz is called *gossan* in this country, *chapeau de fer* in France, *Eiserner Hut* in Germany, and *pacas* or *colorados* in South America. Amongst the colours thus produced iron stains usually predominate; but green, blue, black, or red stains may indicate the presence of copper, nickel, manganese, and other metals. It has already been noticed that metallic sulphides usually become oxidised near the surface, the abundance of iron pyrites in mineral lodes thus furnishing both the ferruginous capping of hydrated sesquioxide, as well as the chalybeate waters which stain the neighbouring rocks.

Similarly, copper sulphides yield at the surface the oxides, melaconite and cuprite, or the carbonates, malachite or azurite. The so-called copper bog of Merioneth is a turf impregnated with carbonate of copper, derived in this way from the copper lodes in the neighbouring hills, and formerly worked and burned in kilns for the extraction of copper. Galena becomes changed at the surface into cerussite or anglesite, and argentiferous galena may produce a mixture of horn silver and cerussite, the associated zinc blende being removed as soluble zinc sulphate, a result which greatly facilitates subsequent smelting operations. In the same way, carbonates of iron and manganese yield gossans of brown hæmatite and pyrolusite, and even stable minerals like gold and cassiterite become loosened from their enveloping sulphides, and are left in the gossan in a state of purity, which renders their extraction easy. A porous gossan is more promising than a dense one, since porosity implies the removal of metallic compounds, which, at lower

levels, will be found intact. The famous Mount Morgan gold deposits were first obtained by quarrying the deep frothy and cavernous gossan which forms the summit of the mountain. Figs. 90 and 91 illustrate the effect of chemical action near the surface of a lode. The decomposition generally ceases at the water level, below which

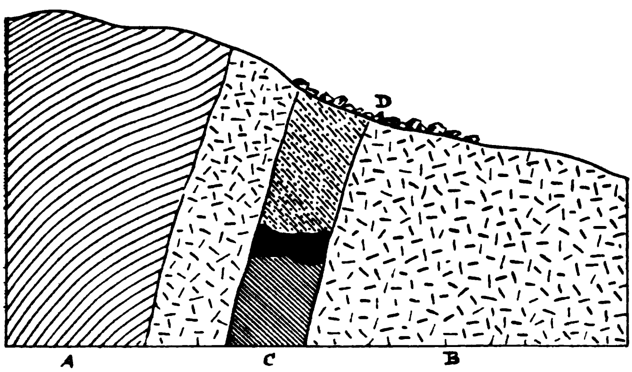


FIG. 90.—DECOMPOSITION OF MINERAL LODE NEAR THE OUTCROP.
A, Slates; B, Porphyry; C, Lode, upper part ferruginous, separated from lower undecomposed part by a layer of rich Copper Ore; D, Gossan.

the character of the lode sometimes changes completely. Thus, a lode which yields chloride of silver in its upper decomposed part, may become a copper-bearing lode below the water line, where the copper sulphide remains unoxidised and insoluble.

Thus gossan is of double importance to the miner It not only indicates the existence of metallic ores below, but also contributes to the formation of "free milling" ores in preference to more complicated compounds. The commercial value of the ores of the Broken Hill lode of New South Wales is considerably reduced below the water line, not only on account of the greater expense of

working the deeper portions, but also on account of the presence of blende, which has been oxidised and removed from the upper part.

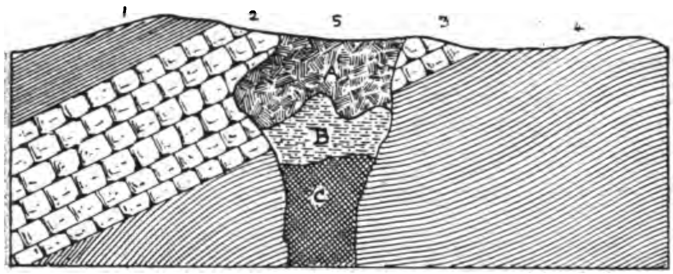


FIG. 91.—DECOMPOSITION OF ZINC ORE NEAR SURFACE IN BELGIUM.
1, Coal measures; 2, Carboniferous Limestone; 3, Dolomite; 4, Schists; 5, Lode, consisting of A, Calamine; B, Silicate of Zinc; C, Blende.

The prospector must carefully note any surface indication of an unusual nature. In Sicily the sulphur-bearing limestone is altered to gypsum near the surface, and in Italy a white powdery substance in the cracks of

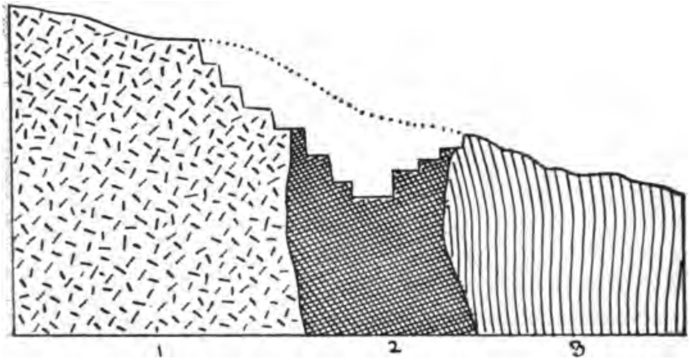


FIG. 92.—PYRITES QUARRY, RIO TINTO (*after Phillips*).
1, Porphyry; 2, Pyrites; 3, Schist.

serpentine rocks often marks the thin threads of asbestos, which, when followed up, unite into valuable masses of this useful substance.

*Association of Minerals (paragenesis).*—The presence of one mineral may sometimes indicate the existence of others with which it is usually associated. Many cases of such paragenesis of minerals have already been mentioned, some of which are collected into the following table:—

PARAGENESIS OF MINERALS.

| Associated Minerals. | Additional Minerals often present, singly, or in groups. |
|---|---|
| 1. Galena, Blende ... | Iron pyrites, silver ores, spathic iron, diallogite, quartz, calcspar, or barytes. |
| 2. Chalcopyrite, Iron pyrites ... ... | Ditto. |
| 3. Gold, quartz ... | Pyrites, galena, blende, spathic iron, diallogite, calcspar; but never fluorspar or barytes. |
| 4. Cobalt, Nickel ... | As No. 1. |
| 5. Tin-stone, wolfram | Quartz, lithia-mica, tourmaline, topaz, fluorspar. |
| 6. Platinum, Chrome Iron ... ... | Serpentine. |
| 7. Cinnabar, Tetrahedrite ... ... | Pyrites, spathic iron, diallogite, quartz, calcspar, or barytes. |
| 8. Rock-salt, gypsum... | Anhydrite. |
| 9. Sulphur, gypsum ... | Anhydrite, celestine. |
| 10. Magnetic chlorite ... | Garnet, pyroxene, hornblende, epidote, pyrites. |

In prospecting for minerals in soft rocks near the surface a pointed steel rod is sometimes used to probe the ground. In this way the French burr stones, buried in clay, the lumps of kauri gum, a resin found in New Zealand swamps, and the phosphate nodules of Carolina, are found; while the soft pockets of umber and hæmatite in the Carboniferous Limestone of the Isle of Man and Furness are also indicated by piercing the rock in a similar manner.

*Quarries or Open Works.*—Having found a mineral deposit, the next process is to decide upon the best method of "winning" it. The common notion that gold is dug, stone is quarried, and metals are mined, is by no means correct. Many metals are quarried, as, for example, the tin stockworks in the killas near Bodmin and St. Austell, the great open cast at Rio Tinto (Fig. 92), the Crossfield hæmatite works, and the Northampton ironstone (Fig. 94). Building stone, also, is sometimes worked in underground mines, as the freestone at Box, Wiltshire, the

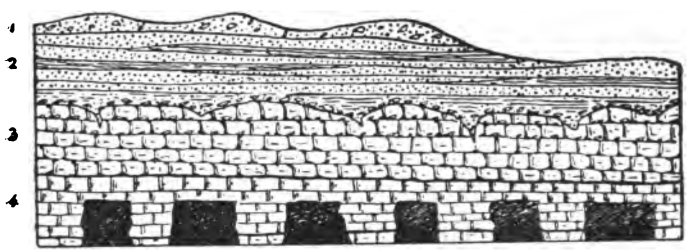


FIG. 93.—GALLERIES IN CHALK PIT, CHISLEHURST.
1, Superficial Gravel; 2, Thanet Sands; 3, Chalk with Flints; 4, Compact Chalk, worked in galleries.

Dudley limestone in S. Staffordshire, slate at Festiniog, and the stone of Burdiehouse, near Edinburgh (see Fig. 93.)

The obvious advantages of quarries over underground mining are to some extent counterbalanced by the necessity of removing useless cover or overburden, and the loss in the surface value of land caused by extensive excavations.

Let us first consider the case of a detrital deposit, the value of which depends upon (1) whether it occurs in superficial river gravels or sea-beaches without overburden; (2) or whether it lies under a few feet of over-

burden only; (3) or, as deep leads beneath so much cover that mining is necessary; (4) or whether the deposit is rich or so poor that satisfactory results can only be obtained by treatment on a large scale. In general the economical working of placer deposits will depend upon the facility with which water can be brought to hand for the purpose of breaking-up the gravels. This is effected either by booming or by hydraulic mining.

In booming, a reservoir is constructed and suddenly

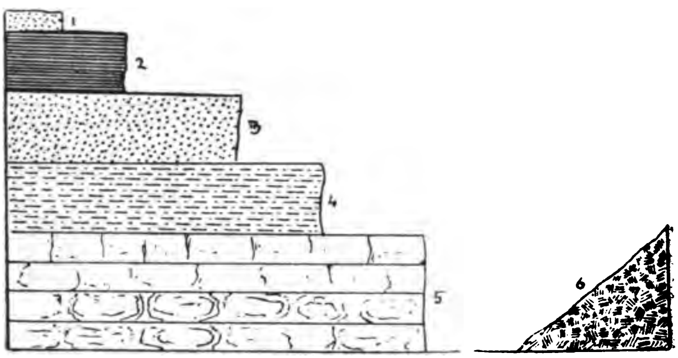


FIG. 94.—IRONSTONE QUARRY, NORTHAMPTON OOLITE.
1, Soil; 2, Clay; 3, Sand; 4, Sandy Clay; 5, Ironstone Beds; 6, Rubbish from Overburden.

discharged upon the gravel beds, the contents being washed into sluices in which the heavy minerals are retained by a specially constructed bottom with cross-pieces, called riffles, nailed across at convenient distances. In hydraulic mining, water at high pressure is secured by damming the higher part of the valley. Powerful jets are then directed against the gravel banks, which are washed into sluices as above. The two essentials for successful hydraulic mining are plenty of water and sufficient fall, both of which obtain in California, but not in Australia.

One great difficulty attaching to hydraulic mining is the disposal of the large mass of tailings, without injury to the adjoining properties. The space on which these tailings accumulate is called dumping ground, to which they must often be confined by specially-constructed dams. In the absence of dumping ground below the workings, the tailings must be raised to a higher part of the valley by the hydraulic elevator.

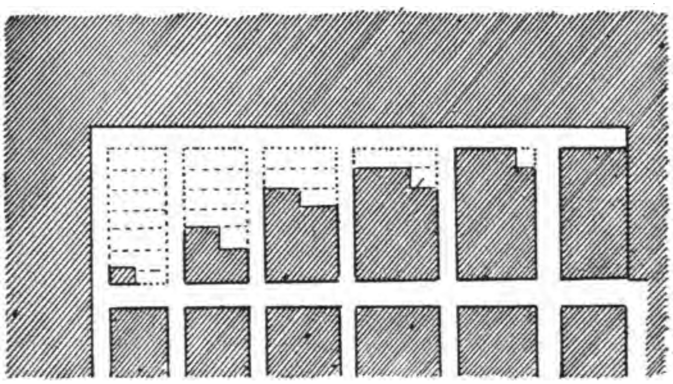

FIG. 95.—PILLAR AND STALL WORKING, SHOWING METHOD OF REMOVING THE PILLARS.

In connection with superficial workings mention may here be made of subaqueous dredging. Some alluvial gold is obtained in this way, as well as phosphatic nodules in the river beds of Carolina, Baltic amber and the bog iron ore of Swedish lakes.

In quarrying it is usual to follow the dip until the overburden becomes too great to remove. The strike is then followed, until a line of quarries is opened in the hill sides. If the cover cannot be profitably utilised, it is applied as far as possible to the restoration of the surface.

*Bed Mining.*—When the overburden is too thick to remove, the bed is reached by shafts, inclines or levels called adits, according to the dip of the bed and the contour of the surface. Liquids may be pumped up from bore-holes, as in the case of petroleum and brine from rock-salt beds. In the disused Pary's mine in Anglesey, advantage is taken of the oxidation of copper sulphide to form soluble copper sulphate, by pumping up the water and extracting the copper by scrap iron.

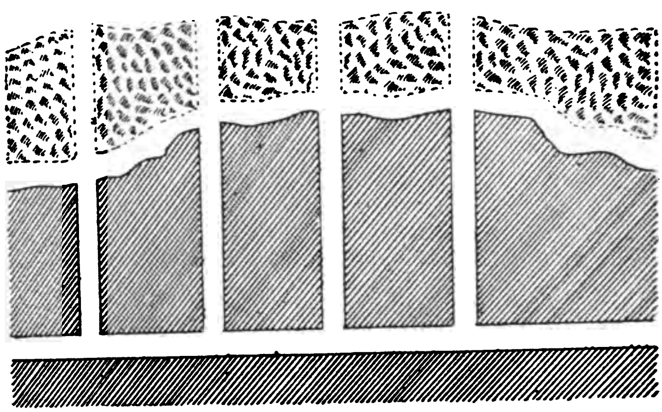

FIG. 96.—LONGWALL WORKING.

In sinking shafts it is well to avoid, if possible, any superficial sandy beds which might be full of water, and require strong walling. Alternations of strata, also, often render extra planking necessary where the walls are unstable, and very watery strata, like the Triassic water-stones, may require a tubbing of cast iron.

When the bed is reached it is systematically removed in such a way that the roof is supported during the excavating process One method of doing this is to leave

pillars at suitable distances apart. This method, known as *pillar and stall* working (Fig. 95), involves a considerable loss of material if the pillars are left intact. To obviate this, the pillars are often finally removed, beginning at the boundary of the mine, and allowing the roof to subside gradually.

In another system of working, called the *Longwall* method, no pillars are left at all, the mineral being worked in long faces backwards from the boundary or *vice versa*,

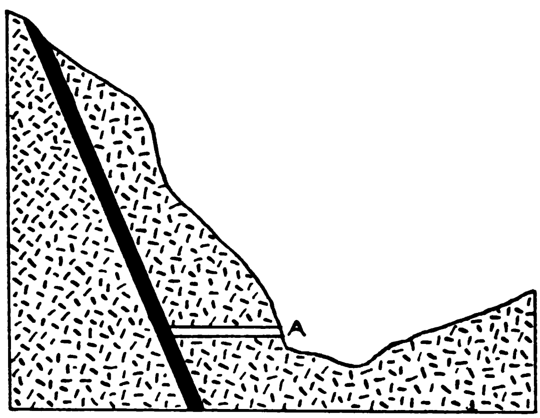


FIG. 97.—INFLUENCE OF SURFACE CONTOUR.

and either allowing the roof to subside, or stowing the excavated parts with rubbish from the seam (Fig. 96).

Special precautions must be taken according to the nature of the roof and floor of the seam. Soft, shivery shales make a less reliable roof than compact, solid rock; and soft floors are liable to *creep*, or rise upwards under the influence of the adjacent pressure.

*Vein Mining*.—Before sinking a shaft to intersect a mineral lode, the hade of the lode, as well as the dip of the strata and character of the country rock, should be

carefully determined, as upon these will depend the placing of the shaft so as to command as much of the lode as possible with the least amount of cross cutting. The stability of the walls and expense of propping and pillaring will also depend on the inclination of the walls of the lode. The surface contour will also determine the position of adits, as seen in Fig. 97. In the excavation of the lode only the rich parts are removed, the rest being left to support the hanging wall. The distribution of these rich parts, as we have already seen, is often very

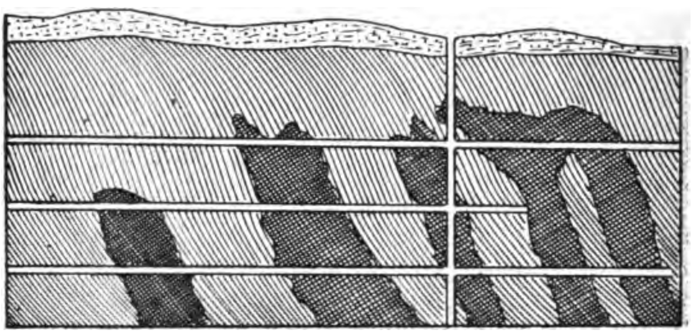

FIG. 98.—LONGITUDINAL SECTION OF A LODE, SHOWING CROSS CUTS INTERCEPTING SHOOTS OF ORE.

irregular, an example of which is given in Fig. 98, showing the shoots of ore reached by cross cuts at Snailbeach lead mine, Shropshire.

The rich parts are worked away in steps, either downwards from the floor of the level, called *underhand stoping*, and represented in Fig. 99; or by the reverse process, called *overhand stoping*, shown in Fig. 100.

Irregular deposits are sometimes excavated entirely, leaving hollow cavities when the enclosing rock is sufficiently strong and compact. A good example of this is

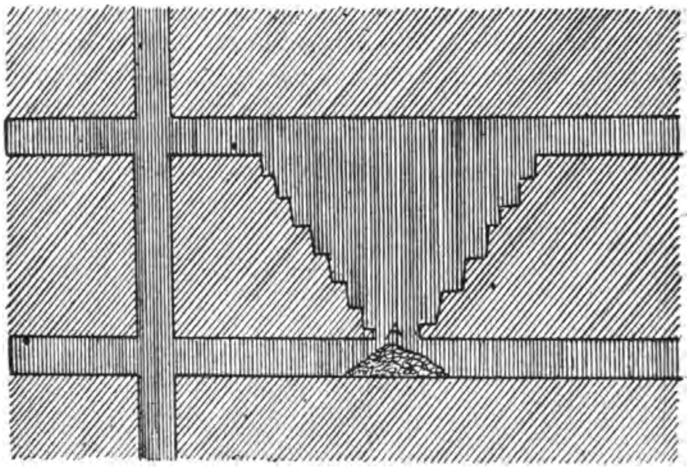

FIG. 99.—UNDERHAND STOPING.
A, Winze.

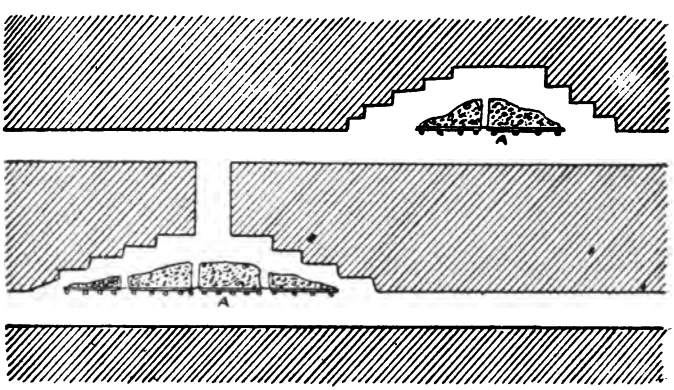


FIG. 100.—OVERHAND STOPING.
A, Staging or Stulls on which the rubbish is placed.

seen in the pockets of hæmatite, called "*churns*," in the Carboniferous Limestone of the Forest of Dean, Fig. 101. In other cases work is commenced at the bottom of the deposit, the cavities being filled up as the work proceeds with the barren rock obtained in excavating; or the upper part is first removed and the roof allowed to subside before the levels beneath are completely excavated.

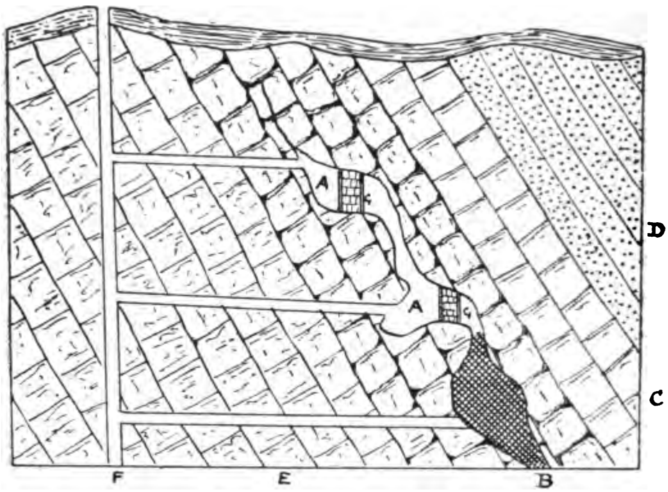


FIG. 101.—CHURNS OF HÆMATITE IN MOUNTAIN LIMESTONE OF FOREST OF DEAN.

A, Caverns from which Ore has been excavated; B, Ore; C, Whitehead Limestone; D, Millstone Grit; E, Grey Limestone; F, Shaft with cross cuts; G, Supporting Pillars of Stone.

Sometimes the varying commercial value of the contents of the lode leads to a complete change in the character of the mine, the gangue becoming more valuable than the ore. Thus some abandoned lead mines are now worked for barytes or fluorspar.

In concluding this necessarily brief outline of the methods of mineral prospecting and development, the

fact is again emphasized that, an economic mineral having been found, there are still many considerations which influence its commercial value. Amongst these are the natural facilities which the locality affords for properly working the deposit, the accessibility of water, timber and fuel, the means of transport, and the expense of treatment of the raw material. Besides this, are the expenses which may be incurred in overcoming natural obstacles, such as subterranean heat and water, noxious gases, and instability of the walls when excavated. Success will depend, therefore, not only on the physical features of the locality, but also upon the geological conditions under which the mineral occurs, as well as its state of purity and its associated products.

Having now exhausted the space set apart for the consideration of minerals, attention will next be given to the economic geology of rock masses.

## CHAPTER IX.

### BUILDING AND ORNAMENTAL STONES.

*Igneous Rocks—Variation in Structure—Joints—Flow Structure—Classification of Igneous Rocks—Principles of Rock Weathering—Causes of Weathering in Building Stones—Conditions affecting Durability.*

*Igneous Rocks.*—Hitherto we have considered only the geological relations of those minerals which are sought for their own sake alone; many of them being compara-

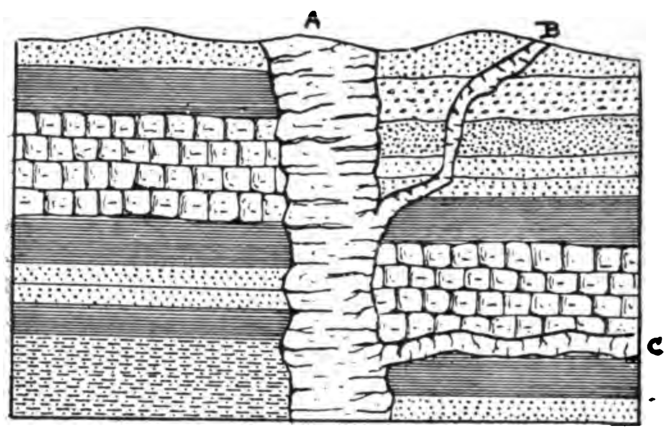


FIG. 102.—DIAGRAM ILLUSTRATING THE RELATIONS OF DYKE, VEIN AND SILL.
A, Dyke; B, Vein; C, Sill or Intrusive Sheet.

tively rare, and few of them entering to any large extent into the composition of rock masses. The rock-forming minerals, however, have also a practical importance, for it is to their various properties that rocks owe their particular value for architectural or engineering purposes. The igneous rocks, to which the present chapter is devoted, occur more or less irregularly in the earth's

crust, and present, therefore, a well marked contrast to the more orderly arrangement of sedimentary strata. For present purposes it will be convenient to classify these rocks as in the following table, which, with the accompanying illustrations, will explain their chief modes of occurrence.

*Modes of Occurrence of Igneous Rocks.*

| | |
|---|---|
| 1. *Volcanic or Extrusive;* viz., rocks which have been ejected from active volcanic vents. | Lava flows (plateau lavas, volcanic piles). Fragmentary forms (agglomerate, breccia, tuff, ash). |
| 2. *Intrusive or Dyke Rocks.* ... | Dykes, Veins. Sills, Laccolites, Necks. |
| 3. *Plutonic;* viz., rocks which have consolidated from a deep-seated molten magma. | Bosses. |

Considerable importance attaches to the recognition of these different types of rock in the field, for not only their composition and texture, but also their extent and the

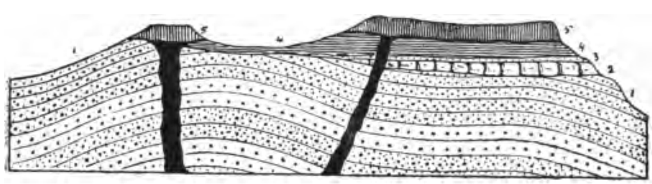

FIG. 103.—CLEE HILLS BASALT.
1, Old Red Sandstone; 2, Carboniferous Limestone; 3, Millstone Grit; 4, Coal Measures; 5, Columnar Olivine Dolerite.

methods of quarrying them will be determined by their mode of origin. Dykes and veins, for example, have generally been formed by the infiltration of more or less vertical fissures, and resemble somewhat the nature of mineral veins. These could only be extensively worked by mining; whereas sills and lava flows, conforming rather to the bedding planes of sedimentary strata or to surface contours, have a lateral extension which enables

them to be more easily quarried. Fig. 102 shows the relationship between dykes, veins, and sills, while Fig. 103 illustrates the lava flow forming the well-known Clee Hills basalt. A volcanic neck, illustrated in Fig. 104, is a mass of igneous rock filling the central pipe of an old volcanic vent. Laccolites are masses of lava, usually rich in silica, and therefore deficient in fusibility, which, being unable to reach the surface, have elevated the superincumbent strata into a dome-shaped mass, as in Fig. 105. It is obvious that such a mass of lava could

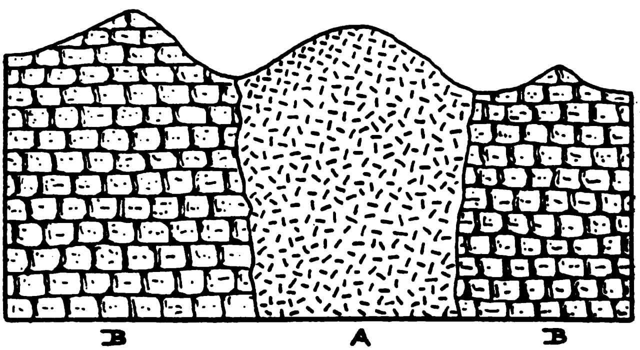


FIG. 104.—NECK OF BASALT IN CHALK OF ANTRIM.
A, Basalt; B, Chalk.

only appear at the surface by the subsequent denudation of the overlying rocks, as seen in Fig. 106. The same may be said of bosses, which are of a still more deep-seated origin (see Figs. 107, 108); but when exposed by denudation at the surface, are often of enormous bulk, and practically unlimited extent in depth. A notable example of a sill of great lateral extension is afforded by the Great Whin sill of Northumberland (Fig. 109), which Prof. Geikie estimates to cover an area of at least 1,000 square miles.

In the investigation of a site upon which a quarry can be profitably opened in igneous rocks, the stone prospector

is of course guided, in the first place, by the loose blocks of stone found upon the surface. If these are *in situ*, and are not merely transported blocks from other localities, a survey must be made, as explained in Chapter I., and the outcrop of the mass of rock determined. If this outcrop runs only in a narrow straight band across the country, it is probably merely a dyke, in which any extensive quarrying would be out of the question; but if

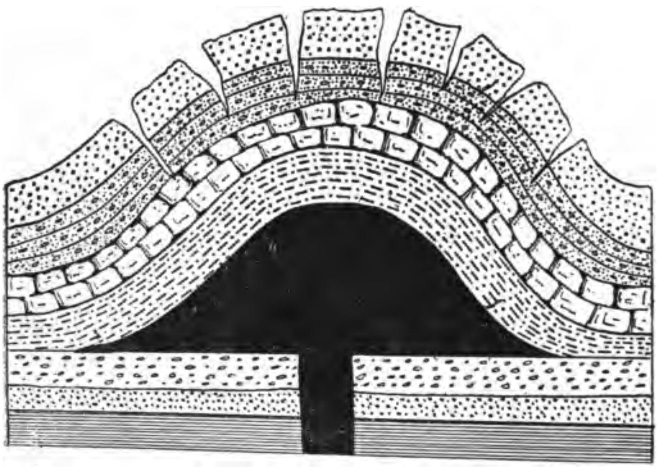

FIG. 105.—UNERODED LACCOLITE (After Gilbert).

the outcrop covers a considerable area, as, for instance, in Fig. 107, the case is different, and a favourable site for a quarry may be selected by giving careful attention to the contour of the ground, for the more durable stone is likely to form elevated ridges, owing to its superior resistance to atmospheric denudation.

*Variation in Structure.*—Igneous rocks may be looked upon in general as resulting from the consolidation of mixtures of fused silicates. Such mixtures, if cooled rapidly, have a tendency to consolidate into an amorphous glass, in precisely the same way as artificial glasses are

produced by fusing together quartz, chalk, and alkaline carbonates, to form mixed silicates of lime, soda, or potash. If, however, the cooling is sufficiently prolonged, devitrification or incipient crystallisation results, the silicates of the alkaline earths being the first to separate, followed by sodium silicates, and finally by potassium silicates and free quartz.

The conditions which determine the order of separation of complex minerals from the molten magma, from which igneous rocks are derived, cannot be properly discussed here. The rate of cooling and the composition of the magma are, however, the chief factors in determining the nature of the resulting rock. Generally, it will be noticed that the volcanic rocks have cooled quickly in comparison with those which have consolidated at a greater depth below the surface. Volcanic rocks, therefore, differ considerably in structure from the plutonic series, although they may both have originated from the same molten magma. Even in the most glassy rocks the tendency to crystallise is always visible. In some cases, the glassy matrix shows radiating groups of embryo crystals, called *spherulites*. At other times, when large crystals of one mineral have developed, a rise in temperature checks the crystallising process, giving the well-known *porphyritic* texture so common in volcanic rocks. On the other hand, a slow and uniform cooling results in a perfectly crystallized structure known as *holocrystalline*. Whether a rock, therefore, is glassy, spherulitic, porphyritic, cryptocrystalline, or holocrystalline, is simply determined by the conditions under which it has consolidated. Changes also occur in the composition of the magma during consolidation, the more basic minerals having a tendency to consolidate first, leaving the magma more and more acid as crystallization proceeds. Soda also tends to separate in the earlier formed crystals, leaving potash predominating in the glassy base.

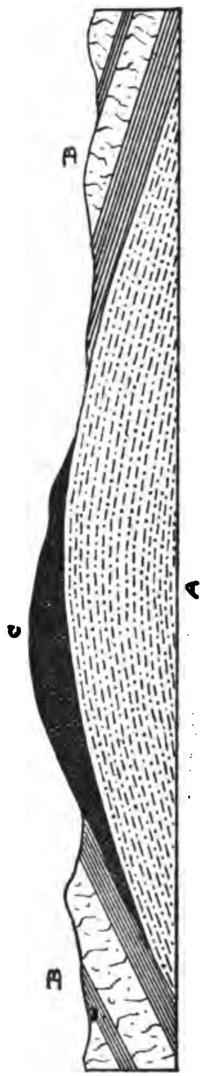


FIG. 106.—ERODED LACCOLITE, CORNDON, SHROPSHIRE (Wats.)

A, Arenig Shales; B. Lava Flows and Ashes; C, Dolerite forming Laccolite.

Not only the grain of an igneous rock, therefore, upon which much of its value depends, but also its mineralogical composition and consequent durability are largely determined by the conditions under which it has cooled. Even the same mass of rock may exhibit variations in the structure of its different parts. The central portion of a thick lava flow may have cooled slowly enough to

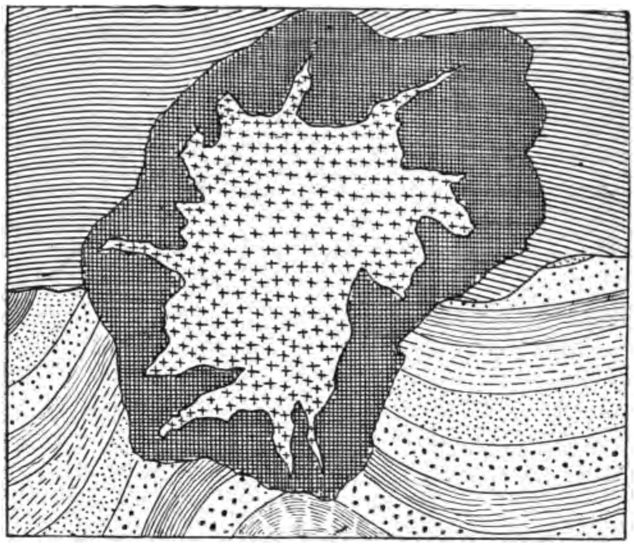

FIG. 107.—PLAN OF GRANITE BOSS, DARTMOOR, showing Zone of Contact Metamorphism.

produce an almost perfect crystalline structure, while the margins may be glassy or imperfectly crystalline.

*Joints.*—Apart from these differences, the rate of cooling also produces other structural features which are of the greatest practical importance. Of this nature are the shrinkage planes, or *joints*, which result from contraction during the cooling process. The most massive igneous rocks are thus broken up into a series of more or

less regular columns by cracks formed at right angles to the cooling surface. The extreme regularity of these joints is remarkable, and has given rise to the suggestion that the direction of the joint planes bears some relation to the crystalline forms of the predominant mineral of which the rock is composed. Thus, the shrinkage cracks in granite often intersect at angles corresponding with the crystalline form of orthoclase; while in basalt the hexagonal jointing planes, intersecting at 120°, have been held to bear some relation to the monoclinic crystallization of augite and labradorite. It seems more probable, however, that the cracks are produced, as Mallet suggests, in the directions of least resistance under the influence of uniform strain during cooling, the form of the joints being such as involve the least expenditure of energy in their production. The hexagonal jointing, so characteristic of basalt, is by no means confined exclusively to this class of rock, but has been noticed in the trachyte of Mont Dore, the pitchstone of Arran, the felstone of Cader Idris, and the phonolite of Auvergne, as well as in volcanic mud of Tideswell Dale, Derbyshire, and the coal of Ayrshire, each being in contact with basalt. It has also been noticed in hæmatite, in palagonite tuff, in quartz veins, and in the ice of glaciers. The direction of the principal set of joints, or *master joints*, being at right angles to the surface of cooling, it follows that any variation in the shape of the cooling surface will alter the direction of the joints. This probably accounts for the curved and twisted columns often seen in prismatic jointing.

The master joints are also generally intercepted by another system of cross joints, at right angles to the former, and sometimes so close together as to lead to a fissile or platy structure, causing the rock to assume almost the appearance of a slate, and enabling it on this account to be quarried for roofing purposes. In

other cases the cross joints are at a greater distance apart, and are sufficiently pronounced to give a bedded appearance to the rock. Such a *tabular* structure is noticeable in many rocks, notably in the granite of Land's End, the dolerite of Burnt Island, Fife, the gabbro of Gimlet Rock, Pwllheli, and of the Cuchullin Hills, Skye, as well as in some of the traps of the Lake District. These cross joints are also occasionally bent, forming *curvitabular* jointing, and the curious *cup-and-ball* jointing often noticed in basalt columns, and breaking them up into articulated segments of various lengths.

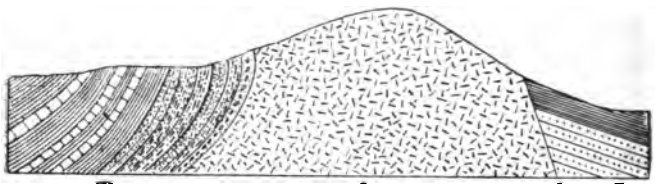


FIG. 108.—SYENITE OF WORCESTERSHIRE BEACON.
A, Syenite; B, Silurian; C, Trias; *f*, Fault.

In some rapidly cooled glassy lavas curved shrinkage cracks are often produced on quite a microscopic scale, causing the rock even to give interference colours in reflected light, from which peculiarity the term *perlitic* structure has been adopted for this phenomenon (Fig. 110). Occasionally the whole rock is broken up by these cracks into small rounded particles.

Intimately connected with the above-mentioned systems of cracks is the *spheroidal* structure exhibited in many weathered basalts and granites, often causing the whole rock to assume the appearance of a loose pile of rounded boulders. In this case we see simply a result of weathering of the rhomboidal blocks produced by the intersecting joint planes, which, being lines of weakness, facilitate disintegration and the rounding off of the corners

of the rhomboids to form spheroids. This same weathering of joint planes leads to the formation of the piles of loose blocks called in granite districts *torrs* or *cheesewrings*, and more rarely to the production of logan or rocking stones.

The existence of joints is of the greatest importance to the quarryman. The separation of the rock mass into large or small blocks by this natural process not only facilitates removal, but also determines the suitability of the stone for various structural purposes. The long, slender basalt colums of the Siebengebirge are so unbroken by cross-joints that they can be used as finger posts ; and many of the monoliths of ancient architectural relics owe their size to the facilities in quarrying afforded by naturally jointed columns without transverse cracks. As an example of this in modern quarrying, we may quote the well-known granite quarries of Augusta and Hallowell, in Maine, U.S., where the horizontal or bottom joints are so well developed that with but little artificial force blocks of stone, 200 feet long and 40 feet wide, can be obtained with a thickness of 8 feet. Such horizontal joints, when pronounced, form a well-defined floor to the quarry, and are often spoken of as bedding joints, although they have nothing to do with bedding in the geological sense. Such joints are never truly horizontal, but run in broad curves corresponding to the shape of the original cooling surface of the molten rock, and in Cornwall they approximate to the shape of the surface contours. When the bedding joints are close together thick blocks are not obtainable, although the stone may still be serviceable for paving blocks and curbs.

Joints are always more conspicuous near the surface of a quarry, since atmospheric weathering is facilitated along the planes of division thus formed. At greater depths they often seem to disappear entirely, but are,

FIG. 109.—THE GREAT WHIN SILL OF NORTHUMBERLAND.

1, Silurian strata; 2, Carboniferous Limestone series; 3, Millstone Grit; 4, Dolerite of the Whin Sill.

nevertheless, still present in a series of close-fitting cracks. Percolation of water may even have resulted in the infiltration of a cementing film of calcite, silica or iron oxide between the joint planes, giving a delusive appearance of solidity to a mass of rock which, if quarried in large blocks, will perhaps, sooner or later, betray the existence of these joint planes, the cracks opening out under the action of the weather with possibly disastrous

FIG. 110.—PERLITIC STRUCTURE IN GLASSY LAVA.

results. Thus the joints in some American norites are so fine that on a polished surface they appear only as faint parallel lines, as if cut with a diamond. It is doubtful whether such rocks can be safely used, owing to the danger of the joints opening out under prolonged exposure. These microscopic joints sometimes spoil a block of stone by opening out during the operations of shaping, even although the force of blasting has been successfully withstood.

The shape of a quarry should be largely determined by the direction assumed by the master joints and bedding joints. One set of principal joints should form

the face or back of the quarry, and another set, usually approximately at right angles to the first, should form the working *ends* or *cutters*. If the bedding joints are highly inclined, the floor of the quarry should not be made so that these joints incline *directly* towards it, in spite of the greater ease with which the stone is thus got, for such a method is a fertile source of accidents, and the blocks are just as easily obtained if the beds incline slightly to one side. In blasting, advantage should always be taken of the joint planes, avoiding, wherever possible, the necessity of moving the blocks up a rising bed. Neither must it be taken for granted that the direction of the joint planes will remain constant for long distances, although they are sometimes traceable for miles across the country in some Cornish granites.

*Flow Structure.*—The onward movement of a partially cooled lava stream causes a dragging out of the crystals in long lines, producing a banded structure, and often an interwoven appearance, which in some porphyries gives a striking character to the rock when cut and polished. By the dragging out of certain unstable minerals, such as nepheline, and their arrangement in more or less parallel lines in the rock, subsequent decomposition may produce a distinctly fissile structure, resembling that of ordinary slates, and some phonolites are on this account quarried for roofing purposes.

For convenience we now collect together in a summarised form the names of the principal structures noticeable in igneous rocks, with the meanings usually attached to them in geological literature. Some of these are not visible without the aid of the microscope and a thin section of the rock, while others can be seen in a hand specimen.

*Porphyritic :* A rock in which one or more of the crystals (*phenocrysts*) are developed on a larger scale than the rest.

*Spherulitic:* Globular aggregations of embryo crystals in a glassy lava.

*Lithophyse structure:* A rarer form of the above, in which the spherulitic spaces contain concentric layers of spherulites and other minerals.

*Orbicular:* A rock with spheroidal aggregates of crystals, with or without radial or concentric arrangement.

*Pegmatitic or graphic structure:* A granite in which quartz and felspar, by simultaneous development, have mutually intergrown.

*Ophitic structure:* Common in dolerites and diabases, when large crystals are interpenetrated by pre-existing minerals.

*Banded structure:* A grouping of crystals or embryo crystals in bands in the direction of flow of a lava.

*Holocrystalline or granite structure:* A complete mass of crystals without glass. The individual crystals may exhibit their proper crystallographic outlines (*idiomorphic*), or may be moulded on to pre-existing crystals (*allotriomorphic* or *zenomorphic*).

*Microcrystalline structure:* A minute form of the above.

*Cryptocrystalline* or *Hemicrystalline structure:* A compact structure formed by an admixture of crystallites, crystals and glass.

*Scoriaceous structure:* Vesicular or cavernous appearance produced by gas cavities.

*Amygdaloidal structure:* Produced by the infilling of vesicles with secondary alteration products.

*Columnar structure:* A result of contraction during cooling, leading to the development of joints.

*Spheroidal structure:* The result of weathering and exfoliation of jointed blocks, whereby spheroidal blocks are produced.

*Perlitic structure:* Microscopic jointing, sometimes exhibited in glassy rocks.

*Drusy structure:* Hollow cavities on the walls, of which crystals are developed.

*Classification of Igneous Rocks.*—In no part of practical geology is there more need for care in accurate description than in the nomenclature of rocks. The loose way in which such general terms as granite are made to include rocks of widely different composition and character is calculated to increase the confusion which prevails throughout the stone quarrying industry as to the real nature of the rocks included under the head of building stone. The object of the accompanying table, therefore, is to assist in naming rocks correctly according to their structure and mineralogical composition.

CLASSIFICATION OF IGNEOUS ROCKS.

| | Structure. | Acid Group. | Intermediate Group. | Basic Group. | Ultra-basic Group. |
|---|---|---|---|---|---|
| Plutonic | *Holocrystalline* | Granite | Syenite Diorite | Gabbro | Peridotite |
| Intrusive | *Microcrystalline* | Quartz-porphyry or Elvan Granophyre | Felsite Porphyrite | Dolerite Diabase Lamprophyre | Serpentine |
| Volcanic | *Partly or entirely glassy* | Rhyolite Obsidian Pitchstone | Trachyte Andesite Phonolite | Basalt Tachylite | — |
| | *Characteristics* | Silica 80-65% Specific gravity below 2·75 Free quartz always present Dominant felspar is orthoclase | Silica, 70-55% Specific gravity, 2·8 Free quartz absent Both orthoclase and plagioclase felspar present | Silica, 60-45% Specific gravity, 2·8-3·0 Quartz absent Orthoclase felspar rare Olivine often present | Silica, 50-35% Specific gravity, 2·8-3·4 Little or no felspar Olivine abundant |

The system is not scientifically perfect, owing to the fact that there are so many varieties of rocks which graduate insensibly into one another. For practical use, however, it is sufficient and simple in application, the horizontal columns referring to structure only, and the vertical columns to mineral composition.

From the above table we see that the same magma may give rise to a variety of rocks according to the conditions of consolidation. An acid magma, or one containing a high percentage of silica, if slowly cooled at great depths in the earth's crust, will give rise to granite, while at the same time it may inject dykes with more rapidly cooled elvans, or pour out at the surface the glassy rhyolites, obsidians or pitchstones. All these rocks will have the same ultimate chemical composition, but will differ essentially both in structure and crystallisation. In the same way a basic magma may form a gabbro, a dolerite or a basalt, according to the circumstances under which it has solidified.

The minerals which enter into the composition of the igneous rocks may be divided into two classes, *original* and *secondary;* the original constituents may also be subdivided into *essential* and *accessory* ingredients. For convenience we shall have occasion to refer to the following groups of minerals, arranged as far as possible to enable the reader to carry easily in mind their general chemical composition. The list is not, however, intended to be exhaustive.

Of these minerals the acid rocks contain chiefly those which are rich in silica, viz., Groups III. and IV., while the basic rocks have a larger proportion of Groups I. and II. We have now to see how this grouping of minerals affects the durability and economic value of the stone.

*Principles of Rock Weathering.*—In the first place it is not to be expected that igneous rocks will be as durable

CHIEF ROCK-FORMING MINERALS IN IGNEOUS ROCKS.

| | Original. | Secondary. |
|---|---|---|
| I. Iron oxides and sulphides | Magnetite<br>Ilmenite<br>Hæmatite<br>Chromite<br>Pyrite | Limonite<br>Marcasite |
| II. Ferro-magnesian silicates | Amphibole<br>Monoclinic Pyroxene<br>Rhombic Pyroxene<br>Biotite<br>Olivine | Epidote<br>Chlorite<br>Serpentine |
| III. Alumina-alkaline silicates | Felspars: Orthoclase<br>Sanidine<br>Microcline<br>Albite<br>Oligoclase<br>Labradorite<br>Anorthite<br>Nepheline<br>Leucite<br>Muscovite | Zeolites<br>Kaolin |
| IV. Silica | Quartz | Chalcedony<br>Opal |

as those of a sedimentary origin. Being consolidated far from the influences of atmospheric agencies, the minerals of which the crystalline rocks are formed are not always chemically stable. In consequence of this an endless series of chemical transformations is afterwards set up in the rock, leading to the formation of secondary products of a more permanent nature. The sedimentary rocks, on the other hand, and especially those which have resulted from mechanical agency, may be looked upon as the products of weathering and disintegration of igneous masses under atmospheric influences. In them chemical equilibrium has been to a great extent re-established by the removal or alteration of the less stable minerals, and further alteration is not on this account so likely to take place. For the same

reason the secondary minerals of an igneous rock will, from the nature of their origin, be generally more durable than the primary constituents from which they were derived, so that serpentine, epidote and kaolin are far less liable to chemical alteration than the olivine, hornblende, or felspar, of which they are the altered products. Other considerations, however, tend to complicate the question of durability in building stones, amongst which we have first to consider the difference in the conditions of weathering of a stone when built into a wall as compared with the more rapid process of disintegration under the surface of the earth. Weathering also must not be confounded with alteration; the former contributes to the disintegration of the rock, but the latter may increase the stability and hardness of the material, a fact specially noticeable in certain sandstones.

*Causes of Weathering in Building Stones.*—We may briefly summarise the principal causes of weathering under the following heads:—

1. *Mechanical Action of the Atmosphere.*—Alternations of heat and cold have a remarkable power of disintegrating certain rocks. In the arid regions of Montana, Merrill states that the surface is often covered with fresh, angular chips of black andesitic rock, quite free from chemical change. Dark, close grained, massive rocks are most subject to this action. Even agate pebbles are cracked by heat in Arabia Petrea. Expansion and contraction will also loosen the cement joints in masonry, letting in moisture and facilitating disintegration. The mechanical action of the wind has often an abrasive effect on even the hardest rock; plate-glass windows have soon lost their transparency under the action of blown sand, and inscriptions on tombstones soon become illegible on exposed surfaces. This action

is, of course, greatest near the surface of the ground.

2. *Chemical Action of the Atmosphere.*—Under the influence of water, carbonic acid and other atmospheric constituents, many minerals are quickly attacked. Rocks containing sulphides, protocarbonates and even protosilicates undergo ***oxidation***, other minerals become ***hydrated***, and holes are left on the surface of the stone by the removal of the altered minerals in ***solution***.
3. *Expansion of Water by Freezing.*—This is a most fruitful source of disintegration in those building stones which are very absorbent of moisture, to which further allusion will be made.
4. *Growth of Plants.*—The walls of ancient masonry have their destruction accelerated by the growth of lichens and mosses, whose rootlets find their way into the smallest cracks. It is only the harder and more durable stones which produce this growth, since soft rocks disintegrate too rapidly for the plants to get any hold upon them. It is probable that the organic acids produced by the decay of organic matter may still further accelerate decomposition.

*Conditions affecting Durability.*—The rate of weathering is influenced by many circumstances, of which the following are important :—

1. *Crystalline Structure.*—A coarse grained rock is generally more susceptible to the above-mentioned agencies than one of close or medium grain, since not only are coarse rocks more absorbent of moisture, but the weaker minerals expose a larger surface to the action of disintegrating agencies.
2. *Mechanical Structure.*—Joint planes, as already mentioned, facilitate weathering, affording lines

of weakness along which the component minerals are exposed to attack by percolating moisture. The danger of hidden joint planes has previously been alluded to.

3. *Mineral Composition.*—The relative durability of the different rock-forming minerals will be further discussed in dealing with the building stones in detail. A few examples, however, are given here to illustrate the importance of this feature. Some minerals are exceptionally unstable under the action of atmospheric agencies. Pyrites readily oxidises to sulphate, and may even lead to the production of sulphuric acid, which attacks other minerals, causing efflorescence of sulphates, increase of volume, and mechanical disintegration in consequence.

Magnetite changes into the hydrated sesquioxide of iron, causing many dark-coloured igneous rocks, rich in this substance, to turn rusty brown in colour. Even granites may in this manner produce unsightly stains. The ferro-magnesian silicates, such as biotite, hornblende and augite, also undergo iron oxidation with a consequent ferruginous discolouration. Silicates containing protoxides of iron, manganese, or lime, are attacked by carbonated water with the liberation of calcite, a change which causes some igneous rocks to effervesce under the action of acids almost as freely as limestone.

Felspars, especially those containing soda and lime, are also liable to this action. The separation of calcite in veins and cracks is a frequent phenomenon in many rocks, and is invariably a source of weakness, owing to the solubility of the calcite in carbonated water. Merrill states that the felspars in some Philadelphia buildings de-

compose so readily that preventive means have been resorted to by painting the surface.

4. *Locality*.—Climate and atmospheric purity have an enormous influence upon the durability of rocks. Rapid alternations of heat and cold have, as explained above, a marked effect even upon compact rocks. The atmosphere of cities contains, in addition to carbonic acid, distinct traces of sulphurous acid, nitric acid, and hydrochloric acid, which, dissolving in rain water, exert a potent influence upon many minerals. Many building stones which would prove durable in a pure country atmosphere rapidly succumb to the injurious effects of the impure air of towns. It follows naturally from this that certain aspects are more unfavourable than others. In Britain, for example, building stones prove more durable on a northern than on a southern aspect, where they are more exposed to the influence of heat and moisture.

5. *Position in the Wall*.—Stones which exhibit any stratified or foliated structure, or any tendency to a fissile banded structure, such as phonolite, should be placed with the planes of bedding or banding horizontal, in which position they will not only absorb less water, but also will be less liable to disintegrate and flake off by the effects of frost or changes of temperature. The least absorbent stones should be used in the lower courses, where ground moisture is likely to exist.

6. *Dressing*.—All crystalline rocks are more durable if the natural cohesion of the crystals is not disturbed by the impact of hammer and chisel. It is obvious that a surface obtained by shattering the constituent minerals would be less able to withstand the action of the weather than the natural rock face.

## CHAPTER X.

### BUILDING AND ORNAMENTAL STONES *(Continued.)*

*The Granites—The Quartz Porphyries—The Syenites and allied Rocks —The Gabbros, Dolerites and Basalts—Serpentines—Fragmental Volcanic Rocks.*

*The Granites.*— A typical granite is a holocrystalline aggregate of *felspar*, *quartz* and *mica*. The felspar, usually about half the bulk of the rock, is generally the potash alumina silicate called *orthoclase;* but other species, containing more or less soda, such as *albite*, *microcline* or *oligoclase*, are frequently present. The mica may be the white variety, *muscovite*, or the dark ferro-magnesian mica, *biotite*. *Hornblende*, and more rarely *augite*, may also be present. There is consequently much variety in the granites, depending upon the presence or absence of the above constituents. Accessory minerals, such as *apatite*, *magnetite*, *pyrite*, *sphene*, *zircon* and *garnet*, are by no means uncommon, while *schorl* or black *tourmaline* occasionally gives a character to the rock. Fig. 111 represents the appearance of a thin section of a hornblendic granite under the microscope; while Fig. 112 gives an idea of the beautiful arrangement of tourmaline crystals in the variety of granite known as *Luxullianite*.

In estimating the durability of granite we must consider the stability of each of its constituent minerals, since a complex rock is soon disintegrated by the breaking down of one alone of its components.

Quartz may be regarded as chemically unalterable under atmospheric influences, although, from its brittle nature, mechanical disruption may result from changes of temperature. Most of the felspars, however, are readily attacked by water and carbonic acid, becoming

kaolinised in a manner which may be represented in the following equation, taking soda felspar, albite, as an example:—

$$\underset{\text{Albite.}}{Al_2O_3.\ Na_2O.\ 6SiO_2} + 10H_2O + CO_2 = \underset{\text{Kaolin.}}{Al_2O_3.\ 2H_2SiO_3} + 4H_4SiO_4 + Na_2CO_3.$$

The sodium carbonate, and possibly the silica also, may

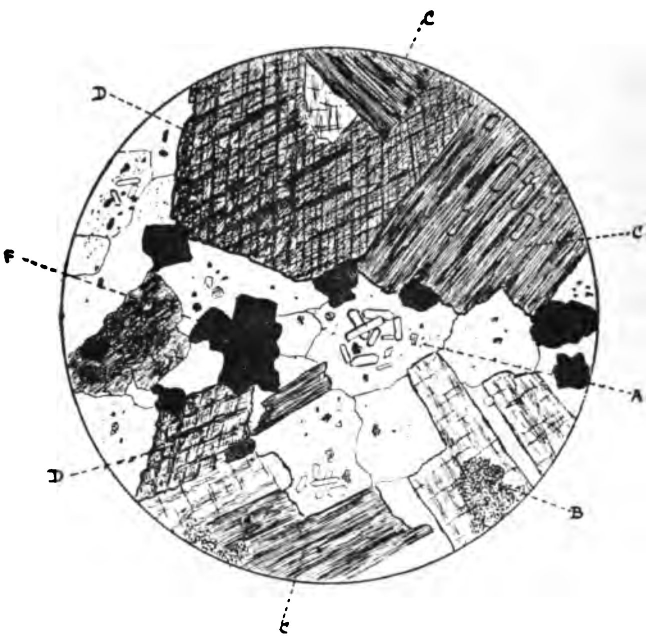


FIG. 111.—HORNBLENDIC GRANITE, DALBEATTIES, KIRKCUDBRIGHT. A, Quartz enclosing Apatite Needles; B, Orthoclase, somewhat kaolinised; C, Biotite; D, Hornblende with characteristic cleavage cracks; F, Magnetite.

be entirely removed in solution; or the silica may be redeposited in the form of opal or hyalite.

Now, felspar is a mineral of very variable composition, and it has been established that the potash felspars decompose much less readily than those which contain

soda or lime. The composition of the felspar is, therefore, an important factor in the determination of the durability of granite.

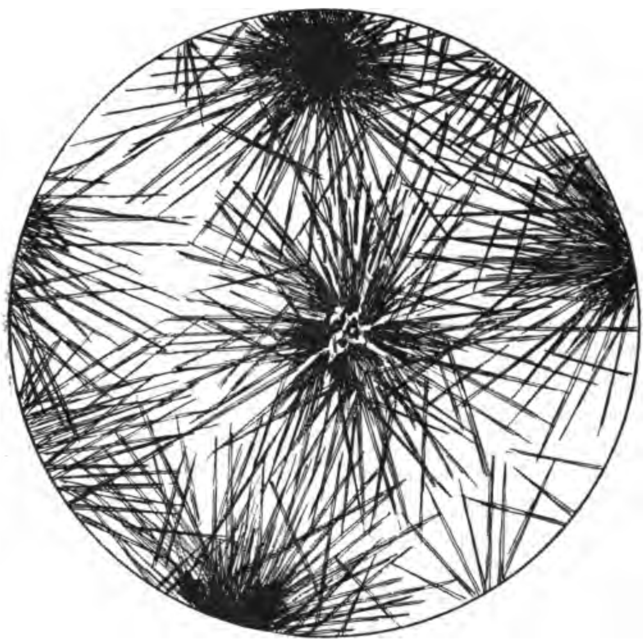

FIG. 112.—GRANITE FROM LUXULLIAN, CORNWALL,
Showing Quartz Crystal, filled with Tourmaline Needles. Black tourmaline, or schorl, is a common or accessory mineral near the margins of the Cornish bosses. This rock, called Luxullianite, makes a beautiful ornamental stone, when polished, showing large pink orthoclase felspar crystals in a dark ground of schorl, with a little quartz.

With regard to the mica, the ferro-magnesian variety, biotite, is a great source of weakness to granite rocks, tending to decompose into chloritic and ferruginous products; but the white potash mica (muscovite) remains remarkably fresh in disintegrated granite, and is on this

account an abundant constituent of the resulting sedimentary sands and clays, in spite of its fissile structure, and the ease with which it can be penetrated by moisture.

With regard to hornblende there is a great deal of uncertainty as to its durability. The dark-coloured varieties, however, yield at first ferruginous decomposition products along their cleavage planes, and ultimately break down into an earthy ochreous residue. Its presence is preferable to biotite, nevertheless, and it undoubtedly confers a high degree of toughness upon the rock. The presence of such accessory minerals as magnetite and pyrite is objectionable, owing to their tendency to decompose into the hydrated sesquioxide of iron, as already explained. The breaking down of the basic minerals, biotite, hornblende and magnetite, produces a red stain or rust upon the joint planes, which sometimes penetrates for a considerable distance into the rock. This rusted granite was formerly rejected as useless, but in America there is a disposition to utilize it in conjunction with lighter coloured varieties for the sake of contrast.

The depth to which kaolinisation takes place has some practical importance, not only as indicating the probable durability of the stone, but also as determining the amount of top rock which must be removed before the sound unweathered stone is reached. Thus the granite of Columbia can be removed with pick and shovel to a depth of 80 ft., and in the Transvaal kaolinisation is said to extend to at least 200 ft. As a building stone, however, it must be remembered that the chemical changes which so readily affect the felspars and micas in the quarry, are almost inappreciable in the walls of a building; while its slight absorptive power, except in those of open texture, renders it but little liable to disintegration by frost.

Granite possesses a remarkable susceptibility to changes of temperature, which tend both to mechanical disruption and the development of superficial cracks and fissures, resulting sooner or later in a scaling of the surface. It is stated that at the burning of a church at Lamerton the granite nave was destroyed, while the sandstone tower remained intact, with the exception of the window jambs and sills, which happened to be granite. This action of heat upon granite has been turned to advantage in quarrying this rock in India. Wood fires are built upon the surface of granite ledges, whereby slabs of rock six inches thick, and as much as 60 × 40 ft. in area, have been split off. It is not improbable that the rapid decay of certain granite structures, notably the Alexander column at St. Petersburg, is due to extremes of heat and cold; but whether this phenomenon is due to the unequal expansion of the component crystals in the direction of their crystallographic axes, or to the large number of fluid cavities enclosed in the quartz crystals, is not known with certainty.

The hardness of most granites enables them to take a high polish, the perfection of which may, however, be marred by the presence of much mica in large crystals, or of porphyritic felspars, which tend to split out along the cleavage planes. The best granites should contain small mica crystals evenly distributed, and should be of small or medium grain. Uniformity is occasionally spoilt by patches of a different grain, or by dark bunches, known as basic secretions, caused by the aggregation in the molten magma of the darker coloured iron bearing minerals, hornblende, biotite or magnetite. The variable proportions of coloured minerals occurring in granite, produce a large variety in the tints assumed by this rock. Pink felspars, green hornblendes, augites or epidote, and black biotite combine to produce effects

which place granite in the front rank, both as a useful and ornamental building stone.

*The Quartz Porphyries.*—Quartz porphyries or elvans may be looked upon as granitic rocks which have cooled too quickly for the development of a perfect holocrystalline structure, certain crystals, well developed and first to crystallise, being enclosed in a more rapidly cooled micro-crystalline matrix. The porphyritic crystals, called *phenocrysts*, are usually quartz or felspar, or both of these minerals. Many of these rocks are very handsome when polished, especially when the colour of the phenocrysts is in harmony with the reddish tone of the base. The Cornish elvans, occurring in dykes penetrating Devonian rocks, form a series of very variable appearance. These rocks have usually a microcrystalline ground mass enclosing phenocrysts of felspar, quartz and often mica. Occasionally tourmaline in stellate groups, as in Fig. 112, replaces felspar. The Ordovician intrusive rocks of Carnarvon are often of a similar nature, some of which, as at Yr Eifl and Nevin, contain augite in place of biotite; while others at Nant Ffrancon have a micropegmatitic ground-mass. The Threlkeld quartz felsite, quarried near Keswick, has secondary epidote and serpentine, replacing hornblende, the value of which minerals is seen in the rough surface always kept on paving stones of this material. When these rocks contain a spherulitic or pegmatitic groundmass they are usually called *granophyres*, a beautiful example of which is that of Carrock Fell, in Cumberland, which contains pale augite and felspars in well-developed phenocrysts. The peculiar beauty and striking contrast exhibited by these rocks, and revealed only in the polished specimen, make them more valuable for decorative relief than for use on a large scale as building material. As a rule they are characterised by great hardness and toughness, and are extremely durable,

being without much grain or fissure, and it seems almost unintelligible that they should hitherto have been used only as local road metal. They must not, however, be confounded with the intermediate porphyries to be described in the following group.

The still more quickly cooled granite rocks forming the acid lavas or rhyolites, and the volcanic glasses obsidian and pitchstone, are not of much practical use. The loose and earthy texture of the rhyolites unfits them for polishing or for use as a durable building stone; while the jointed condition of the obsidians, combined with their brittle conchoidal fracture, making it impossible to obtain blocks of any size, have limited them to their primitive use in the manufacture of prehistoric implements.

*The Syenites and the Allied Rocks.*—Passing now to the intermediate groups of rocks, we have a series differing mainly from those previously described in the absence of quartz. With a decrease in the percentage of silica there is a corresponding increase in the proportion of iron oxides and plagioclase felspars, with a consequent inferiority in durability to rocks of the acid type. Many of the true syenites, however, consisting of orthoclase and hornblende, with only a small proportion of plagioclase and mica, are very durable, and but little liable to discolouration from ferruginous decomposition. There is much confusion in the application of the term syenite, most of the hornblendic granites having been wrongly called by this name. The difficulty is increased also by the insensible way in which the hornblendic granites graduate into true syenites, and by the origin of the name itself, which was first applied to the hornblendic granite of Syene, the ancient name for Assouan, in Upper Egypt. True syenite is rare in this country, although it is much quarried in Arkansas. This latter variety is characterised by the presence of nepheline or elæolite,

and is therefore a *nepheline syenite.* The presence of this mineral, as well as the predominance of soda felspars, adversely affects the durability of this rock.

A similar class of rocks, in which plagioclase felspar predominates, is called *diorite*, of which various types are characterised by the nature of the ferro-magnesian constituent. The well-known Penmaenmawr stone is an enstatite diorite, which also contains a little quartz. The well-developed parallel joints of this rock make it eminently suitable for paving blocks of a tough and durable nature. The orbicular diorite of Corsica, known as *Napoleonite*, or *Corsite*, containing globular aggregations of hornblende and felspar crystals, is beautifully adapted for small ornamentation when polished.

The porphyritic varieties of the intermediate rocks are variously grouped as porphyries and porphyrites, and possess considerable interest from their extensive use by the ancients. The famous red porphyry of Egypt contains phenocrysts of hornblende and felspar, which, by their decomposition, have yielded the manganese-bearing epidote, to which the red colour of the rock is due. Other varieties of porphyry are characterised by the presence of labradorite felspar and augite much decomposed into green chlorite and epidote, giving a characteristic appearance to such rocks as the "*verde antico*" of Greece, quarried from remote times between Sparta and Marathon. The Lambay porphyry of Ireland is of a similar nature, and rivals in beauty the classic rock of ancient Greece. Being without grain or cracks, these rocks are difficult to work, and their extensive use by the ancients is a monument to their skill and patience in cutting and polishing.

The volcanic equivalent of syenite is termed *trachyte*, that of nepheline syenite is *phonolite*, while that of diorite forms *andesite*. The trachytes and andesites are too porous in texture for practical use. Phonolites, although

specially liable to disintegration, owing to the instability of the nepheline and other felspathoid constituents, leucite, hauyn, and nosean, have been used, on account of their fissile structure, for roofing purposes.

*The Gabbros, Dolerites, and Basalts.*—The essential constituents of these rocks are a lime-soda-felspar and a


FIG. 113.—GREENSTONE, PWLLHELI.

A diabase in which the ophitic structure is well represented by the Augite, A, interpenetrated by Plagioclase, B. The black mineral is Titaniferous Magnetite (Ilmenite). The felspars are cloudy with decomposition product.

pyroxene. *Gabbro* proper contains a monoclinic pyroxene, while *norite* has a rhombic pyroxene. Olivine is generally present in a more or less decomposed state, while the hornblende-gabbros contain hornblende in addition to pyroxene. More or less iron oxide, in the form of magnetite or ilmenite, is generally present in all

these rocks. From what has been already said on the subject of weathering, it will be readily understood that the basic rocks are more unstable than those of a more acid composition, the large proportion of iron oxide, ferro-magnesian, and soda-lime minerals all contributing

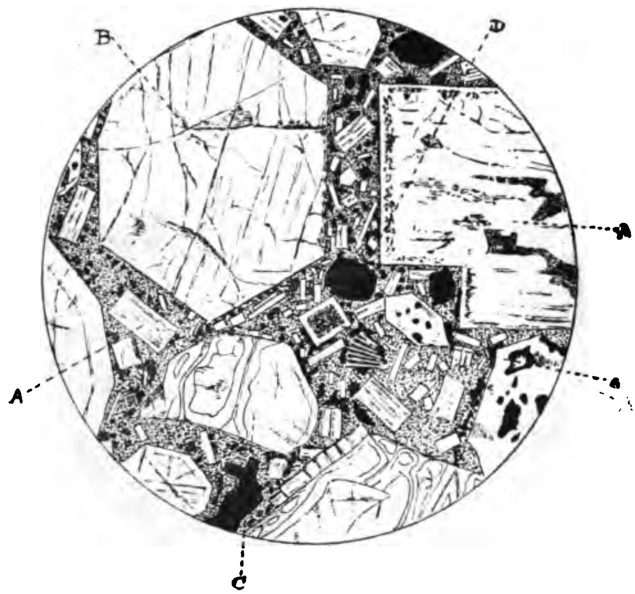


FIG. 114.—PORPHYRITIC BASALT, EDINBURGH.
A, Plagioclase Felspar; B, Augite; C, Olivine; D, Magnetite.
The felspars contain inclusions of the ground mass, in the centre as well as in peripheral zones. (*After Cole*).

to a greater susceptibility to chemical decomposition. The frequent staining of all these rocks by green chloritic and serpentinous decomposition products, led to their being generally classed under the head of *greenstones*, a term abundantly used on the older geological survey maps, and including a large range of very different rocks, such as diorite, diabase, gabbro, dolerites, and picrite.

Diabase differs from gabbro chiefly in structure. The felspar has been amongst the first to crystallise, and the ferro-magnesian constituent is therefore moulded upon and interpenetrated by felspar crystals, causing what is known as *ophitic* structure (see Fig. 113).

The volcanic equivalent of the basic rocks forms the

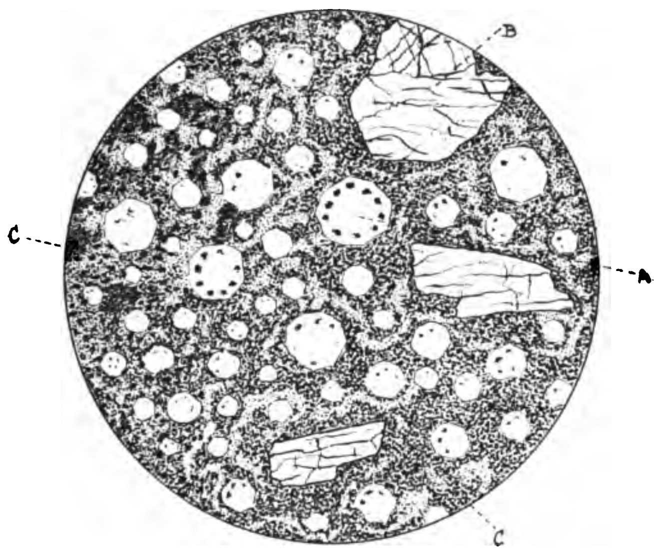


FIG. 115.—LAVA, VESUVIUS.
A, Leucite crystals, with characteristic peripheral inclusions; B, Augite; C, Ground mass crowded with small crystals of Leucite, granules of Nephelin and glassy matter.

well-known class of *basalts*, of which the more crystalline varieties are termed *dolerite*. Fig. 114 is a typical example of an olivine dolerite, while in Fig. 115 a modern leucite basalt from Vesuvius is represented.

The family of *lamprophyres*, or mica traps, are a series of fine grained holocrystalline rocks, containing an abundance of biotite and other ferro-magnesian silicates,

and abundantly represented in dykes and sills in the North of England.

The dark, sombre colours of the basic rocks, due chiefly to the abundance of iron oxide, unfits them for architectural work, and their compact structure makes them sometimes difficult to work. The Clee Hills basalt is extensively used for road metal, and being tough and fine grained, is peculiarly suitable for heavy traffic, making also very little mud or dust. Some basalts seem to possess a remarkable resistance to crushing force, a specimen of Antrim basalt, from Ballymena, requiring, according to Mr. Wilkinson, the enormous force of 32,130 lbs. upon a one-inch cube.

Basalt was somewhat extensively used in ancient Egyptian sculpture, and Vesuvian lava was employed for corn-mills in Pompeii. In modern times an attempt has been made to take advantage of the easy fusibility of basic rocks by melting them and pouring into moulds as a substitute for carved ornamental stone work. Quick cooling produces a black glass *(tachylite)*, but slower cooling produces a more crystalline mass. The work was abandoned chiefly on account of the bad weathering properties of the resulting rock. The stages in the weathering of basic rocks under the influence of water and carbonic acid may be summed up as follows :—

1. Carbonates are formed, and silica liberated, causing the rock to effervesce like limestone, as explained under the head of granite, the protoxide bases becoming soluble bicarbonates.

2. Ferruginous decomposition, resulting from oxidation of the protoxide of iron, leading to brown stains of hydrated sesquioxide of iron.

3. Further oxidation of pyrites, if present, with possible formation of sulphuric acid and efflorescent sulphates.

4. Final residue of loose, powdery kaolin, or hydrated silicate of alumina.

*Serpentines.*—Of the ultra-basic rocks, serpentine alone needs any description. The rich colouring and variety exhibited by this rock, as well as the ease with which it can be cut and polished, have contributed to raise it to the front rank as a decorative stone. The variations in

FIG. 116.—SERPENTINE,
Showing characteristic mesh structure of altered Olivine rock, with veins of Steatite and black Oxide of Iron.

colour exhibited by serpentine are due chiefly to the presence of iron in various stages of oxidation, but a great deal of its varied appearance is caused by its intimate admixture with other minerals, such as steatite, calcite, diallage, olivine, chrome iron, and pyrites (see Fig. 116). Serpentine is invariably a product of altera-

tion of other rocks rich in magnesian minerals, especially olivine and non-aluminous pyroxene, and it is to the incompleteness of this alteration that its many veins, streaks, and blotches are due. Olivine passes into serpentine by simple hydration; pyroxene by hydration, combined with a loss of silica and lime. The rock is invariably badly jointed: even where large blocks can be obtained they are liable to fracture under strain, rendering the rock useless where great strength is required. The very veins which contribute to its beauty are usually lines of weakness in the rock, temporarily filled up with secondary products.

Being attacked by both hydrochloric and sulphuric acids, serpentine is not adapted for outdoor use in the atmosphere of towns. When weathered, the polished surface becomes dull and greasy, the veins especially showing a tendency to crumble and open out into deep furrows. In spite, therefore, of its being practically non-absorptive, its use should be strictly confined to indoor work. Its comparative softness, also, and the ease with which it can be scratched, renders it unfit for positions where abrasion is likely to occur.

The serpentinous marbles will be considered under another head, as these rocks are not true serpentines.

Amongst the useful products of serpentine rocks are soapstone (*steatite*) and *asbestos*. True asbestos is a fibrous variety of hornblende, but the commercial asbestos is *chrysotile*, or *amianthus*, obtained chiefly from Canadian and Italian serpentine. The fibrous, serpentinous residue of the rock, called *asbestic*, is pulverised for use as fire-proof wall plasters, requiring neither hair nor sand.

*Fragmental Volcanic Rocks.*—Fragmental volcanic rocks, in the form of pumice, agglomerate, tuff, and ash, have but limited practical applications. The use of pumice, the bulk of which is dug out of the volcanic ashes of

Lipari, is chiefly confined to polishing purposes in various trades. Volcanic ash, when consolidated by age, may be capable of use as building stone or road-metal; and, as will be seen later, it may even acquire cleavage, and develop into useful slates.

Both the ancient Romans and the modern Italians have used volcanic dust as a mortar, called *puzzolana*, for building purposes. The *tufa*, of which Naples is largely built, is a stone formed by the natural setting of volcanic mud. Under the name of *peperino* it is also used extensively around Rome, and was the prominent stone in the ruined cities of Herculaneum and Pompeii. A similar material, called *trass*, is used in the Eifel district of Germany. The setting properties of puzzolana are due to the carbonic acid of the atmosphere acting upon the silicate of lime in the volcanic dust, forming carbonate of lime, and liberating free silica in a manner already explained. A cement is thus produced which binds the dust into a solid mass.

# CHAPTER XI.

## BUILDING AND ORNAMENTAL STONES *(Continued).*

*Building Stones of Sedimentary Origin—Structural Features of Sedimentary Rocks—Sandstones—Varieties of Sandstone—Sandstones as Building Stones—Geological Age and Characters of the Chief British Sandstones.*

*Building Stones of Sedimentary Origin.*—The fragmental or *clastic* origin of the majority of the sedimentary rocks renders them useless as building stones, unless the constituent particles have been subsequently converted into a compact mass. This may have been effected either by natural cohesion under intense pressure, by the infiltration of a cementing material, or by the development of new minerals by internal chemical changes. These subsequent changes often lead to a complete alteration in the character of the rock, which is then usually classed as *metamorphic*. For our purpose, however, it will be convenient to consider the aqueous rocks and their metamorphic derivatives under one heading, since they differ only in the degree and kind of alteration to which they have been subjected. By this departure from the usual practice of geological text-books, we are able to consider together rocks of similar nature and properties, with a considerable gain in simplicity of classification, the fact that certain metamorphic rocks are probably of igneous origin having a theoretical, rather than a practical interest.

As previously explained, these sedimentary rocks may generally be expected to be of a more durable nature than the crystalline rocks from which they were originally derived, since the more unstable portions of the latter would either have disappeared, or have formed new combinations of a more permanent nature, during

the process of accumulation of detrital deposits. As will be seen, however, the economic value of these detrital rocks is greatly influenced by the subsequent alterations which they have undergone, during which new elements of instability may have been introduced. In examining these rocks, therefore, we must carefully distinguish the original, or *allothigenous*, constituents from those secondary, or *authigenous* components which have been subsequently formed.

*Classification of Rocks of Sedimentary Origin.*

| Mode of Origin. | Siliceous. | Calcareous. | Argillaceous. |
|---|---|---|---|
| 1. Mechanically formed sediments, slightly altered from their original state | *Sands*<br>*Gravels*<br>*Sandstones*<br>*Conglomerate*<br>*Breccia* | *Shell and Coral Sand*<br>*Calcareous mud* | *Clay*<br>*Shale*<br>*Marl*<br>*Silt*<br>*Mud* |
| 2. Organically formed sediments | *Tripolite* | *Chalk*<br>*Limestones and some oolites* | |
| 3. Chemically formed sediments | *Sinter* | *Travertine*<br>*Stalactite and stalagmite*<br>*Onyx marbles*<br>*Oolite and pisolite* | *Kaolin*<br>*Laterite* |
| 4. The above rocks altered by contact metamorphism | *Quartzite* | *Crystalline limestones*<br>*Marbles* | *Porcellanite* |
| 5. Slaty rocks produced from the above by intense lateral pressure or shearing | | *Limestone slate* | *Clay Slates*<br>*Phyllites*<br>*Mica Slates, &c.* |
| 6. Foliated rocks produced by dynamic metamorphism both of sedimentary and igneous rocks | *Quartz-schiefer*<br>*Garnet schist*<br>*Gneiss* | *Highly crystalline and serpentinous marbles* | *Schists*<br>*Gneiss*<br>*Bastard granite* |

In the above table the metamorphic derivatives of the siliceous, calcareous and argillaceous rocks respectively, are placed in the same vertical column as the sedimentary rocks from which they originated.

*Structural Features of Sedimentary Rocks.*—The economic value of the above-mentioned rocks, considered as building stones, depends upon certain structural features which may be considered under the following headings:—

(*a*). *Nature of the bedding planes.*—The stratification may be coarse or fine. Thus we have thickly bedded sandstones and limestones, called *freestones*, thin bedded *flagstones*, and finely laminated *tile-stones*.

(*b*). *Presence of included fossils.*—Many building stones owe their value to organic remains, *e.g.*, madrepore marbles, encrinital marbles. In other cases the absence of these is an essential feature, *e.g.*, statuary marble.

(*c*). *Amount of impurity present.*—Limestones often contain sufficient argillaceous matter to render them useful in making hydraulic cement. On the other hand, the presence of clay-holes deteriorates the value of sandstones. Impurities, also, largely determine the nature of secondary minerals produced by metamorphic changes in the rock.

(*d*). *Amount of absorbed water.*—The presence of much quarry water makes stones liable to injury by freezing. Some sandstone quarries in severe climates are unworkable in winter from this cause. The loss of quarry water by evaporation causes many building stones to become harder on exposure. This effect is confined to the outer crust, and may be due in some cases to the deposition of dissolved silica, iron-oxides, or calcium carbonate; in other cases, to the removal of unstable particles from the outer crust. For this reason all carving and shaping should be done while the quarry water is still in the stone, to avoid breaking the hardened crust after the quarry water has evaporated.

(*e*). *Nature of the cement.*—As will be presently shown, the durability of many stones depends upon the kind of cementing material by which the grains are held together. This applies especially to sandstones.

(*f*). *Nature of the colouring matter.*—Whereas the colours of igneous rocks are due chiefly to their varied mineralogical composition, even the more homogeneous aqueous rocks, such as sandstones and limestones, often possess a variety of colour which determines to no small extent their architectural value. These colours are due chiefly to the presence of carbon or of the various compounds of iron. Traces of carbon produce the blue and black tints of many limestones and slates. Carbonates and sulphides of iron also produce bluish-grey colours. Anhydrous sesquioxide of iron imparts red and brown tints, the hydrous sesquioxide giving yellow hues, and silicates green. From a practical point of view, not only the suitability of the tint, but also its liability to change, has to be considered. The alteration of ferruginous minerals has already been fully discussed. For this reason stones quarried below the water line are specially liable to an alteration in tone from blue-grey to buff, owing to the oxidation of sulphides and protocarbonate of iron. Many light coloured sandstones, also, mellow with age, becoming yellow in tint as oxidation proceeds. Even black carbonaceous matter tends to bleach under exposure, causing a fading, which is absolutely destructive of the rich appearance of many dark stones. Irregular streaks and zonal colouring is sometimes produced in rocks as the result of differential oxidation in the neighbourhood of joints and other divisional planes.

(*g*). *Presence of segregation products.*—In some cases segregation products have a special value in themselves, such as flints in chalk, septaria in clay, or phosphatic nodules. In building stones, however, their presence is injurious, destroying homogeneity, and often, as in the

case of marcasite, introducing unstable patches which subsequently produce unsightly stains and blotches.

(*h*). *Joint planes.*—The subject of jointing has already been discussed with reference chiefly to the igneous rocks. Similar structures are also produced in sedimentary rocks, probably as a result of contraction during drying and consolidation. These joints are usually most clean-cut in fine grained rocks, in which they are often quite invisible until displayed by fracture or weathering. In coarser grained rocks the joints become more irregular.

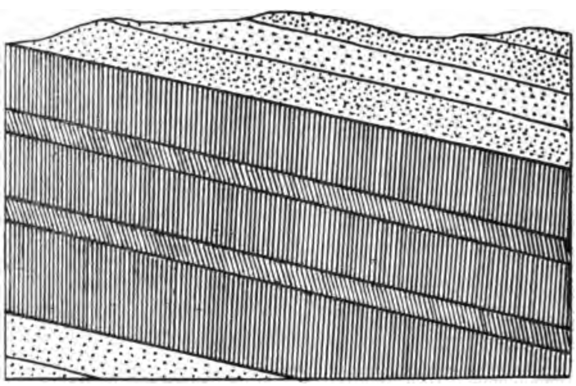

FIG. 117.—DEVIATION OF CLEAVAGE PLANES IN BEDS OF VARYING COMPOSITION.

Whereas in the igneous rocks the joints are perpendicular to the cooling surface, in aqueous rocks they are approximately at right angles to the bedding planes, forming generally two sets, of which one follows the direction of strike, the other that of the dip. In quarrying the strike joints, called "*backs*," form the working face, while the dip joints, known as "*cutters*," run backwards, cutting the former transversely, and often enabling large blocks to be wedged off without the aid of blasting.

(*i*). *Cleavage planes.*—The development of the fissile structure known as cleavage, is for practical purposes confined to the fine grained argillaceous rocks, although imperfect cleavage may be developed in other varieties of rock which have undergone the necessary amount of lateral compression. The direction of the cleavage planes is often persistent over wide areas, and coincides approximately with the strike of the strata, and therefore with the direction of the axes of the principal flexures. The perfection of the fissile structure depends

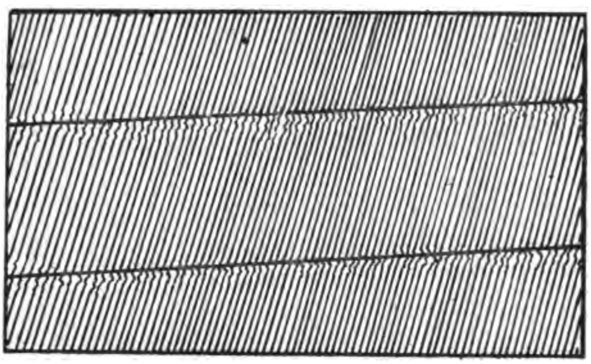

FIG. 118.—WAVY CLEAVAGE NEAR THE JUNCTION OF BEDS.

largely upon the texture of rock. In fine grained argillaceous rocks they are close together and well developed, becoming wider apart and less perfect as the rock becomes coarser in grain and less argillaceous. Sandstones rarely possess any indication of this structure, although a rough semblance of cleavage may occasionally be noted. Small variations in the direction of the cleavage planes may also occur on passing from one bed to another of slightly different composition and texture. (See Figs. 117, 118). Subsequent pressures may develop secondary cleavage planes, making an angle with the

the original cleavage, and effectually spoiling the value of the rock for splitting purposes. True cleavage planes must be carefully distinguished from other fissile structures, due to lamination or jointing. The cleavage of a rock is usually inclined at high angles to the bedding planes, and, as seen in Fig. 119, is always perpendicular to the direction of the pressure which folded the strata.

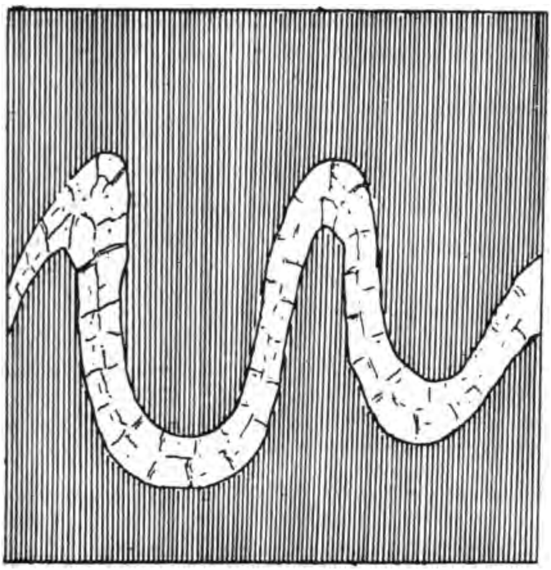

FIG. 119.—PARALLEL CLEAVAGE IN CONTORTED BEDS, THE CLEAVAGE PLANES BEING AT RIGHT ANGLES TO THE PRESSURE.

(*j*). *Foliation.*—The same lateral compression and shearing stress, which produce cleavage planes in certain rocks, may finally lead to the development of schists and gneiss. This structure, however, is of small importance from a practical point of view, as the foliated rocks are of but little use as building stones, owing to the ease with which the planes of foliation break away.

(*k*). *Metasomatosis*.—This term is meant to include all those changes in a rock which result in an alteration in its original composition, either by the loss of some constituents, or by the addition of others. This change has taken place to a greater or less degree in nearly all the sedimentary rocks which are of use as building stones. Examples of metasomatosis will be given in the detailed discussion of the chief groups of rocks, when its practical importance will be fully recognised. Under this heading are included the dolomitisation of limestones, the consolidation of rocks by infiltration of dissolved cements, and even the development of secondary minerals, such as epidote, chlorite, mica and sericite. Such changes are usually the result of atmospheric influences, combined with the percolation of water holding various substances in solution.

(*l*). *Thermal and Dynamic Metamorphism*.—Even without metasomatic changes, the character of a rock may become completely altered by metamorphic processes. Thermal metamorphism may convert a sandstone into a quartzite, or a limestone into a crystalline marble. Dynamic metamorphism may produce structural changes in addition to mineralogical alteration, such as are involved in the passage from clay to slate, schist and gneiss. In such cases the development of secondary minerals is favoured by the presence of impurities in the original rock.

With the above brief allusion to the important characters which are impressed upon sedimentary rocks during their consolidation and conversion into useful building stones, we now pass on to the consideration of these rocks in detail.

*Sandstones*.—A sandstone consists essentially of round or angular grains of quartz, with occasionally other minerals, cemented into a solid mass by silica, carbonate of lime, oxide of iron, or clayey

matter. Of the other minerals which may be present with the quartz grains, felspar and muscovite mica are the most common; but there may be also other accessory minerals in variable quantities, such as biotite, tourmaline, pyrite, garnet, zircon, rutile, grains of glauconite and oolitic grains of iron ore. Being originally derived from the crystalline rocks, the commonest constituents of sandstones are those which are least prone to chemical change, since the more unstable minerals are soon eradicated by selective decomposition. This fact explains the durability of sandstones as building material, as well as its special adaptability for use in the smoky atmosphere of large towns.

The quality of sandstones depends upon two things, viz., the nature of the grains themselves and that of the cementing medium.

The size of the grains determines the texture of the stone, which varies from a fine grained compact rock to a coarse grit with grains as large as a pea. The shape of the grains is also important in its influence upon the amount of interstitial space available for cement. Angular grains usually fit more closely than round grains, and therefore have less cementing material. Such sandstones do not so readily tend to polish under friction, and are specially suitable for grindstones, since they maintain a good cutting surface. The sharpness of the grain depends to a large extent upon their immediate origin, whether derived directly from the disinteggration of igneous rocks, or from pre-existing clastic deposits; for owing to the resistance which quartz offers to chemical alteration, the grains are only reduced by mechanical abrasion.

The nature of the cementing medium is, however, the chief factor in determining the durability and hardness of the stone. This cement varies greatly, both in quantity and composition, the quantity, as already stated,

depending upon the amount of interstitial space between the grains. In some cases the cement is so sparingly present that pressure alone seems to have consolidated the rock to a compact mass. (See Fig. 120.)

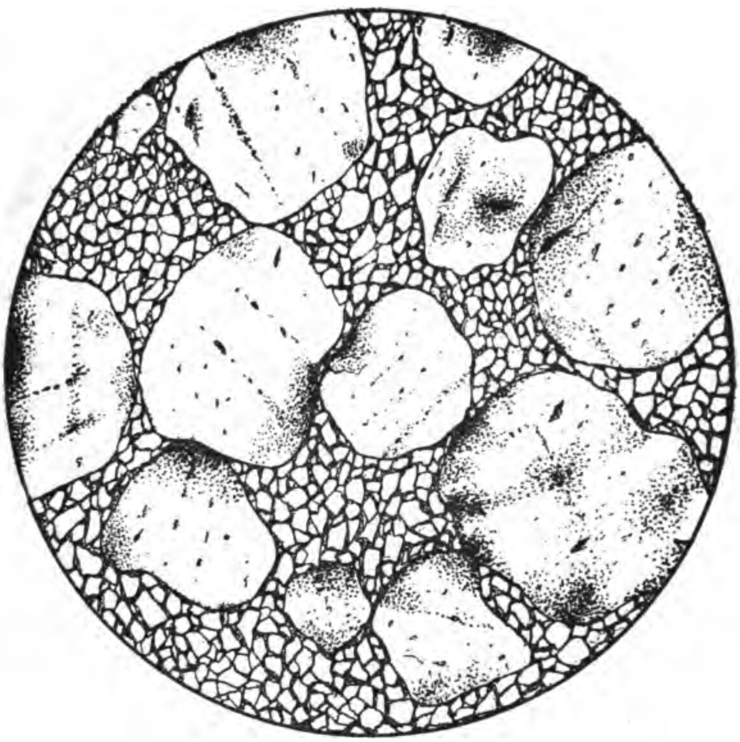

FIG. 120.—SANDSTONE SHOWING QUARTZ GRAINS OF TWO DIFFERENT KINDS.
The larger grains are rounded; the small angular grains fill the interstices, the whole being cemented by secondary silica.

*Siliceous* cements are usually in the form of silica deposited in crystalline continuity with the original grains, of which it appears as an outgrowth, causing

secondary enlargement of clear, transparent quartz (Fig. 121). This feature may be seen in many Triassic sandstones. Wethered suggests that the silica may be

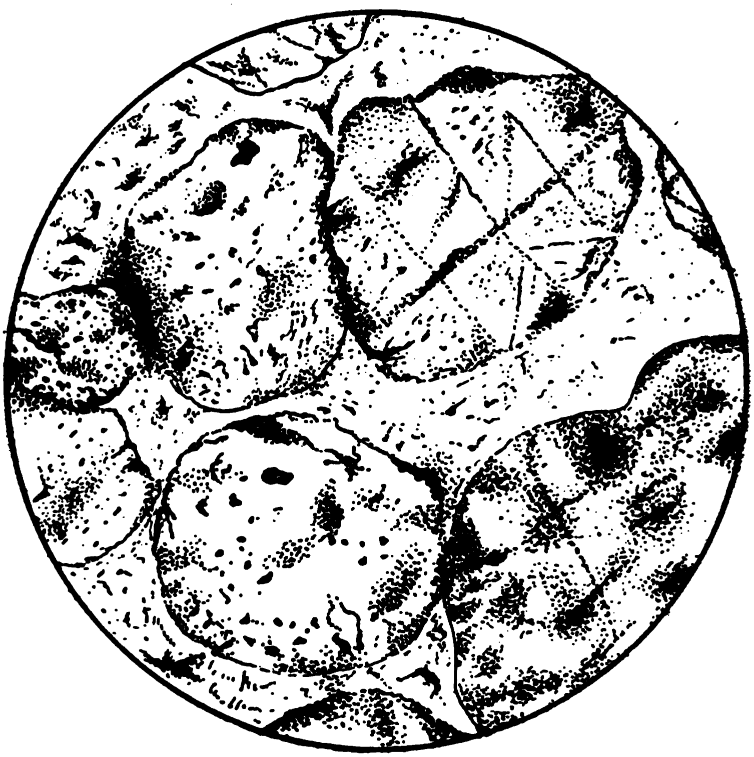

FIG. 121.—LICKEY HILLS QUARTZITE.
The large rounded quartz grains are cemented by secondary silica in crystalline continuity with them, as may be seen by the simultaneous extinction of both the grain and the surrounding cement when viewed between crossed nicols. The primary grains are crowded with minute enclosures.

provided by a slight solution of the original quartz grains themselves at points where they press upon one another. In some cases, however, the cement has been deposited

by the percolation of dissolved silica from without, and has been noticed to have a radial arrangement round the quartz grains. In the Ightham stone of Kent (Folkestone beds), Bonney noticed that the siliceous cement forms a fringe of small quartz crystals, arranged perpendicularly to the surface of each grain. Occasionally, in the neighbourhood of hot springs, the silica occurs in the form of chalcedony. Although siliceous cements give the most durable stone, absorbing but little water, such sandstones are also most difficult to work, and graduate into quartzites which are too hard to be used commercially with advantage. Even siliceous cement, however, may give rise to sandstones of an incoherent nature, owing to the existence of a ferruginous coating between the cement and the original grain.

*Calcareous* cement is nearly always in the form of crystalline calcite deposited from solution, and does not always completely fill the interstitial spaces. When the cementing calcite is present in large quantity, the rock becomes indistinguishable from an impure siliceous limestone, such as the calcareous Grits of Yorkshire and the Kentish Rag of Maidstone; while in the Fontainebleau Sandstone the calcite forms large plates around the quartz grains, giving the whole rock its characteristic rhombohedral cleavage. Although a calcareous cement gives a soft, easily worked stone, it is not so durable, weathering rapidly under the influence of carbonated water, by which the cement is gradually attacked, and the quartz grains liberated. Some sandstones, such as the Caradoc sandstone of Shropshire, contain so large an amount of calcareous matter in the shape of fossil remains that the stone is burnt for lime.

*Ferruginous cement* may consist either of the red oxide or the brown hydrated oxide of iron, which often forms a thin pellicle round each grain of sand (Fig. 122). Such sands are readily decolourised by the action of

acids. Ferruginous colouring matter also frequently accompanies calcareous and clay cements. When taken fresh from the quarry such sandstones may be of a bluish tint, from the presence of ferrous carbonate or finely

FIG. 122.—FERRUGINOUS GRIT,
Showing angular quartz grains embedded in an opaque cement, which consists of a mixture of calcareous and ferruginous matter.

divided pyrites, which rapidly oxidises on exposure to brown and yellow colours. Occasionally, the green silicate of iron, glauconite, in the form of grains representing the casts of Foraminifera, forms the colouring matter of certain Greensands.

*Argillaceous Cements.*—Many sandstones contain fragments of felspar and mica which yield kaolin on decomposition. Many of the felspathic sandstones of the Millstone Grit of Yorkshire, as well as those of the older

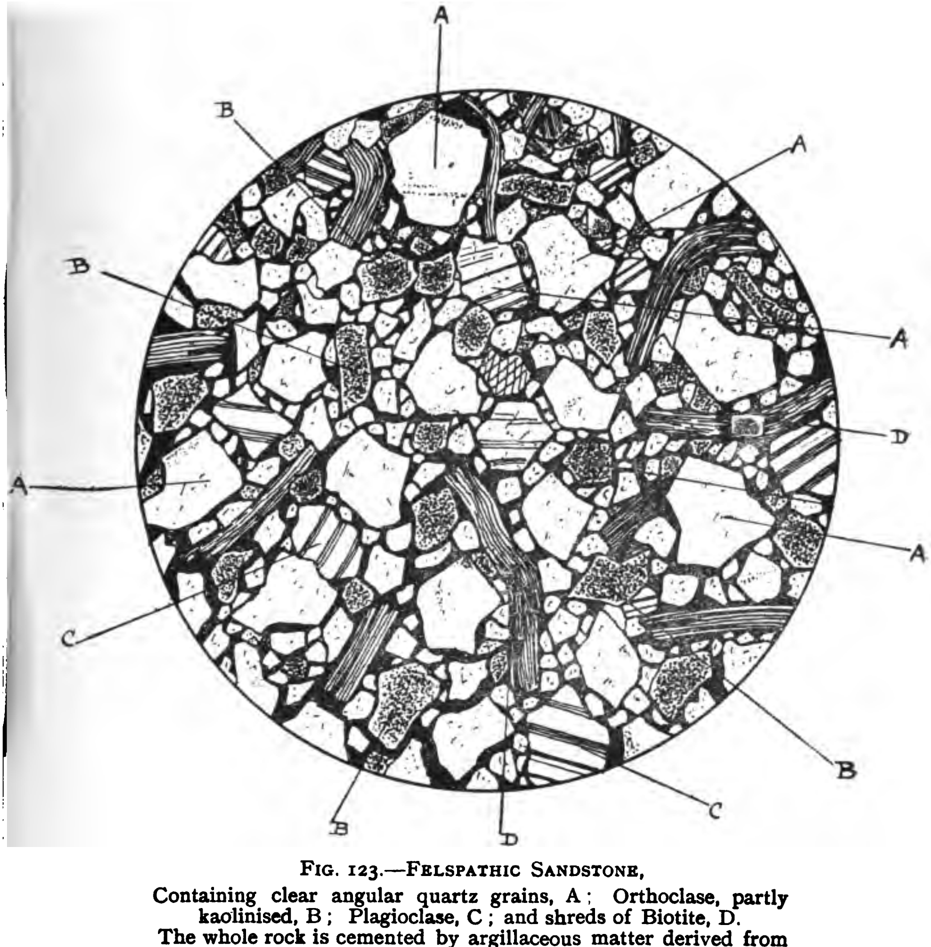


FIG. 123.—FELSPATHIC SANDSTONE,
Containing clear angular quartz grains, A; Orthoclase, partly kaolinised, B; Plagioclase, C; and shreds of Biotite, D.
The whole rock is cemented by argillaceous matter derived from decomposition of the felspars.

rocks of Carnarvonshire, show the felspar in every stage of decomposition, the resulting clay occupying the spaces between the quartz grains, into which it appears to have been squeezed by pressure (Fig. 123). Argillaceous cements seldom yield a durable stone, being very absorptive, and liable to disintegrate by frost. In rare cases other forms of cementing material may be present, such as gypsum or barytes; but such rocks are not of practical importance as building stones.

*Varieties of Sandstones.*—The following varieties of sandstones have received distinct names on account of certain peculiarities either of structure or origin. The most highly metamorphosed varieties, forming the quartzites, are generally too hard and expensive to work as building stones, but are extensively employed for road metal.

VARIETIES OF SANDSTONES.

*Micaceous Sandstone:* A sandstone containing muscovite mica, often deposited in the bedding planes, and causing a kind of fissile structure in many flagstones.

*Felspathic Sandstone:* A sandstone in which felspar fills a part of the interstitial space between the quartz grains.

*Ferruginous Sandstones:* A sandstone in which the cement is coloured by iron oxide.

*Calcareous Sandstone:* A sandstone with a calcareous cement.

*Argillaceous Sandstone:* A decomposed felspathic sandstone.

*Arkose:* A disintegrated granite, or felspathic grit.

*Greywacke:* A rock containing grains of quartz, felspar, &c., cemented by silica.

*Quartzite:* An indurated sandstone, with a siliceous cement.

*Greywethers:* Tertiary sandstones with a siliceous cement, forming the well-known Sarsen stones scattered over the chalk downs of southern England.

*Conglomerate:* Coarse rounded fragments cemented into a compact mass, usually by silica.

*Breccia:* Coarse angular fragments similarly cemented.

*Grit:* A sandstone with sharp, angular grains, generally rather coarse.

*Freestone:* A thick bedded sandstone, capable of being quarried in large blocks.

*Flagstone:* A thin bedded sandstone, splitting readily along the bedding planes to form paving stones.

*Tilestone:* Still more thinly bedded sandstone, often split into thin slabs by exposure to a winter's frost.

*Blue Stone:* A thin bedded shaly sandstone, cemented by silica; a siliceous shale, used for flagging.

*Ripple-marked Sandstone:* A flaggy sandstone showing ripple marks; used for paving.

*Flexible Sandstone:* A felspathic sandstone or quartzite, in which the interlocked quartz grains have a small amount of play, allowing a certain degree of movement.

*Itacolumite:* A felspathic sandstone of a similar nature to the above.

*Sandstones as Building Stones.*—The natural porosity of most sandstones is an objection to their use in damp situations. The absorptive power, however, varies considerably with the degree of coarseness and the nature of the cement. As the porosity diminishes, there is an increase of hardness and difficulty in working, which proves a serious obstacle to their extensive use. The naturally rough surface, also, favours the growth of algæ, lichens, and mosses, and tends to increase its dampness. The most readily worked sandstones, with a calcareous or clayey cement, are specially liable to disintegrate by frost. This defect is specially to be noticed in those cases in which the stones have been laid with their bedding planes in a vertical position, by which flaking under the action of frost is greatly facilitated. The bedding planes should invariably be laid horizontally, unless there is much false-bedding, in which case a vertical position may be more advantageous.

Soft sandstones are also liable to mechanical disintegration by wind-blown sand near the surface of the ground. It is not unusual to find the base of sandstone walls in wind-swept districts scored with deep furrows

from this cause. The chief value of sandstone lies in its chemical durability: neither its crushing weight, nor its resistance to mechanical abrasion, are in its favour.

Permanence of colour is also to be considered. The alteration of "blue hearted" stone on oxidation by the atmosphere has already been mentioned. The occasional presence of unstable minerals, such as pyrites, is also objectionable, and leads to the production of stains and blotches on weathering. Many examples of this may be noticed in the sandstone buildings of Edinburgh, in which pyrites not only speedily weathers to a brown stain, but also finally leaves actual cavities in the stone. Similar cavities are also produced by the weathering out of clay holes and other impurities.

The best sandstones are those which are fine grained and homogeneous in texture, absorbing as little water as possible, and containing only a small proportion of lime and iron.

*Geological Age and Character of British Sandstones.*—The sands of *Recent* formation have not yet been sufficiently consolidated to form building stone, although in some cases they afford instructive examples of incipient consolidation by the cementing action of percolating water containing salts of lime and iron in solution.

Of *Tertiary* sandstones the Greywethers represent relics of Eocene strata which once covered the Chalk of the South and West of England. These are more or less oblong blocks of siliceous sandstone, often of large size, formed by the consolidation of concretionary masses of the Bagshot sands. They were used extensively in the Druidical structures of Avebury and Stonehenge, and are still employed for building, paving, and road-metal. When first excavated from the superficial gravels they are soft and friable, but soon harden on exposure.

*Cretaceous* sandstones are represented by the "Hearthstone" and "Fire-stone" of Surrey, soft calcareous

sandstones mined in subterranean galleries in the Upper Greensand of Godstone. The Carstone of the Lower Greensand (Folkestone beds) is a ferruginous grit, which has been used locally under various names, such as Ightham stone. The Kentish rag formed the material for many churches in Kent, but is rather of the nature of a siliceous limestone. The Wealden deposits contain occasional beds of calcareous sandstone, of which Tilgate stone and Horsham stone are varieties in local use.

The *Oolite* formation contains numerous examples of calcareous and ferruginous sandstones, such as the Calcareous Grits of Yorkshire and the Kellaways Rock.

*Triassic* sandstones are largely quarried in Cheshire and the adjoining counties, both in the Keuper and Bunter formations. The Lower Keuper yields a fine-grained, light-coloured freestone, as well as flagstones. Many of these stones are of great durability and uniformity of texture, and have been employed in some of the finest structures in the Midland counties. Similar beds near Belfast are also quarried, although the stone is often seriously impaired by the numerous igneous dykes by which it is penetrated.

The *Permian* sandstones are usually wanting in consistency and durability, although in the Vale of Eden the lower beds are extensively used for building purposes. The best sandstones of this age are the Mansfield White and Red Sandstones, which are dolomitic, and may be regarded as silicified varieties of Magnesian Limestone.

In the *Carboniferous* series, sandstones occur in the *Yoredale* rocks, *Millstone Grit*, and *Coal Measures*; while in Scotland the *Calciferous Sandstone* yields a valuable white freestone (liver rock), largely used in Edinburgh and Glasgow. The Yoredale beds of Derbyshire and Yorkshire yield fine-grained micaceous grits and flagstones

with very little calcareous matter. The Millstone Grit is a very variable formation, and affords sandstones of several types, from thick-bedded coarse grits to flaggy sandstones. The famous Yorkshire stone is of this age, and is generally hard and durable, with a siliceous cement. Some of the Millstone Grit beds, however, are felspathic. The Coal Measure Sandstones are either micaceous flagstones, or argillaceous and ferruginous sandstones of an inferior quality to the Millstone Grit.

The *Old Red Sandstone* is largely quarried for local use in Hereford and Monmouthshire, and in Scotland yields the famous Caithness, Arbroath, and Dundee flagstones. The former are dark-coloured, bituminous and calcareous sandstones; while the latter are harder and more durable, being extensively used in London pavements. This formation also yields both sandstones and flagstones in Cork and Kerry.

In the *Silurian* strata there are numerous beds of sandstone of local interest, such as the Coniston Grits and Flags, the Downton Sandstone, quarried near Ledbury, the May Hill Sandstone, and the Caradoc beds *(Ordovician)*. These Lower Palæozoric Sandstones are usually hard and siliceous, but sometimes felspathic. The quartzite of the Stiper Stones is of Ordovician Age.

*Precambrian* sandstones have generally been metamorphosed into quartzites, of which examples occur at Hartshill, in Warwickshire, and the Lickey Hills, in Worcestershire. These are usually too difficult to work as sandstones for building, but are extensively quarried for road-metal.

## CHAPTER XII.

### BUILDING AND ORNAMENTAL STONES *(Continued).*

*Calcareous Rocks—Varieties of Limestone and Marble—Calcareous Rocks as Building Stones—Onyx Marbles—British Marbles and Limestones—Slates—Laterite—Tests for Building Stones.*

*Calcareous Rocks.*—Although mechanical action has in some cases assisted in the production of calcareous rocks, the greater part of this group of building stones owe their origin either to chemical or organic agencies. Their composition varies considerably with the conditions under which they have been formed, the purer varieties having originated in deep water, and those which were accumulated nearer the shore being more or less contaminated with argillaceous or siliceous impurities. Most of the massive limestone rocks were, in the first place, a mere accumulation of the fragments of organisms set in a matrix of calcareous mud; but some of those formed in shallow water consist largely of oolitic or pisolitic grains, each of which is built up of successive coats of calcareous matter arranged concentrically around a nucleus of sand or of a minute fragment of calcareous mud or chip of shell. The origin of this oolitic structure (Fig. 124) may have been mere mechanical aggregation, or due to the action of certain lime-secreting algæ (Girvanella). The original structure of all these rocks has been partly obliterated by the tendency to recrystallisation, owing to the solubility of calcium carbonate in natural waters, and its redeposition in the form of calcite. This secondary calcite results not only from the crystallization of the matrix, but also from the conversion of aragonite shells into the more stable form of calcite. In some cases, as in certain oolites, the matrix is partly removed by solution, vacant spaces being left between the grains, as seen

in the Ancaster and Ketton limestones of the Lincolnshire oolite. Generally, however, the matrix assumes the appearance of a crystalline mosaic of calcite, by which means the texture of the rock gradually becomes closer

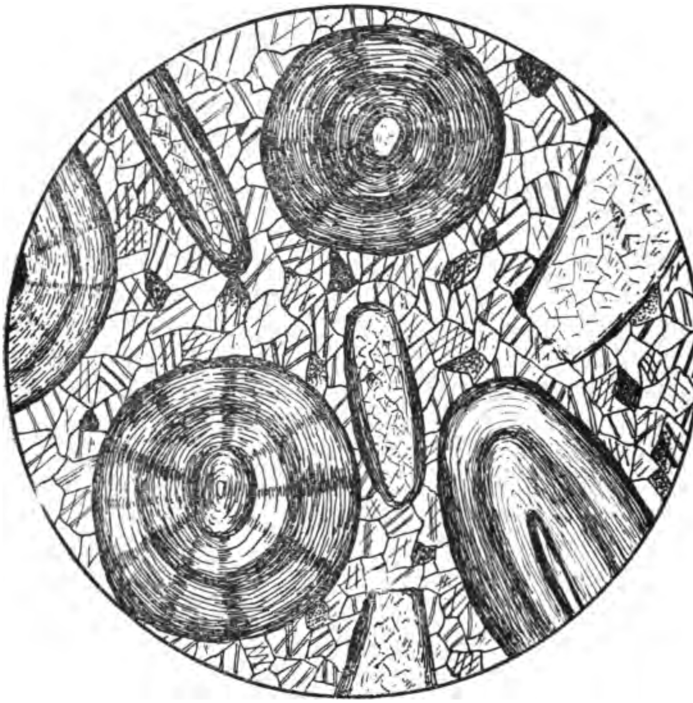

FIG. 124.—OOLITIC LIMESTONE,
The oolitic grains showing concentric and radial structure; the remainder of the slide is occupied by fragments of shells and a mosaic of calcite.

until it is hard enough to take a polish. The limestone then becomes a marble, which, in its typical form, is an aggregate of calcite crystals. By further metamorphism metasomatosis may follow, resulting in the replacement

of part of the calcium by magnesium carbonate, silica, or other substances. Still further changes produce the more highly crystalline marbles, often with indications of fluxional shearing and incipient cleavage (see Fig. 125).

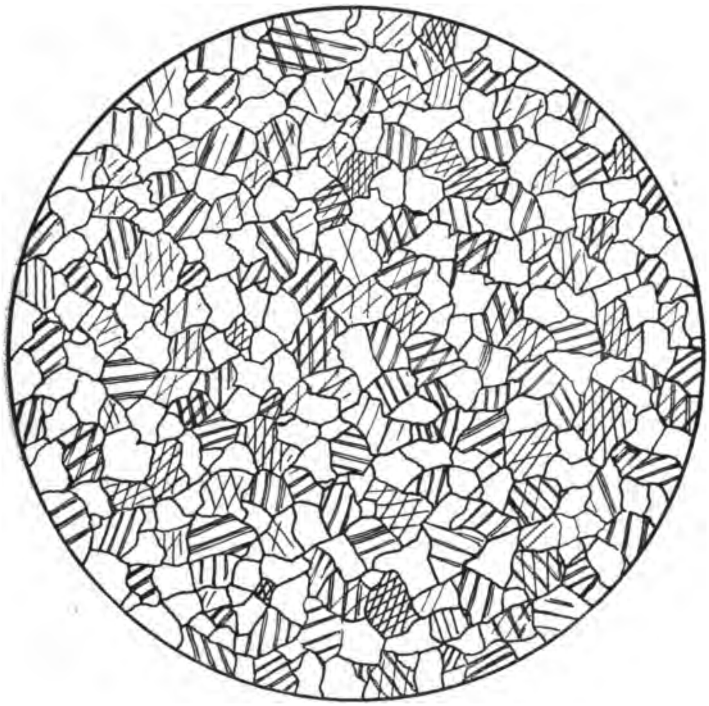

FIG. 125.—STATUARY MARBLE,
The whole rock consisting of an aggregate of calcite crystals.

The character of a limestone depends, therefore,—(1) upon the nature of the original grains, whether organic remains or oolitic aggregations; (2) the extent of re-crystallisation of the matrix and conversion of aragonite

into calcite; (3) the degree and kind of metasomatosis; (4) the extent of thermal and dynamic metamorphism.

*Varieties of Limestone and Marble.*—The above-mentioned characters produce an infinite variety of rocks, of which the following are the better known examples:—

*Coquina or Shell Limestone:* A consolidated calcareous mud, with fragmentary shells, used as a building stone in Florida.

*Lumachelle:* A shell limestone of the Tyrol, in which the shells retain their pearly lining.

*Crinoidal Limestone:* Consolidated fragments of crinoids.

*Fusulina Limestone:* Consolidated fragments of the foraminifer, *Fusulina.*

*Ammonite Marble:* Containing ammonite shells, as at Yeovil (Lias).

*Nummulitic Limestone:* With fossil nummulites.

*Madrepore Marble:* Containing corals, as the *Bird's Eye* marble of Iowa; and the *Buckshorn* marble, or Featherstone of Devonshire, with the coral *Favosites.*

*Chalk:* A pulverulent rock composed of broken shells of foraminifera, sometimes used for building—*e.g.*, Totternhoe stone.

*Oolitic Limestone:* Containing rounded concretionary masses of calcic carbonate.

*Pisolitic Limestone:* A coarser form of the above.

*Dolomitic or Magnesian Limestone:* A limestone in which magnesium carbonate partly replaces calcium carbonate.

*Hydraulic Limestone:* In which mechanical impurities, such as clay or sand, occur in suitable proportions to yield hydraulic cement when ground and calcined.

*Siliceous Limestone:* A limestone containing silica—*e.g.*, Kentish Rag.

*Calcareous Freestone:* A thick bedded limestone, such as many Oolites.

*Lithographic Limestone:* An extremely fine-grained, impure crystalline dolomitic limestone of a grey or yellow colour, suitable for lithography.

*Bituminous Limestone:* Containing bitumen, with its characteristic odour—usually black in colour.

*Travertine:* Limestone deposited by chemical precipitation from calcareous waters.

*Onyx Marble:* A stalagmitic limestone, formed as above.

*Ruin Marble:* A yellowish limestone, which has been minutely fractured and recemented with ferruginous or calcareous cement.

*Landscape Marble:* An argillaceous limestone, showing dendritic markings, probably of iron or manganese oxides—*e.g.*, Cotham marble of Bristol.

*Dolomitic Conglomerate:* A consolidated Triassic beach, in which limestone pebbles have been recemented, often by dolomite.

*Breccia Marble:* Recemented angular fragments of limestone, found in the Isle of Man.

*Saccharoid Limestone:* A crystalline limestone, with the texture of loaf sugar.

*Statuary Marble:* A highly altered limestone, with uniform, waxy texture, usually white and granular—*e.g.*, Carrara and Paros marbles.

*Ophiolite or Ophicalcite:* A crystalline aggregate of calcite and serpentine—*e.g.*, Connemara marble, or Irish Green, and Verde antique marbles.

*Cipollino:* A fine-grained, green marble, with long seams of mica, often arranged in concentric form. A variety from Eubœa was much prized by the ancients. It is now quarried at Saillon, in the Rhone Valley, and polished in thin slabs for ornamental purposes.

*Tiree Marble:* A pink schistose limestone, showing fluxional shearing, with eyes of green salite (diopside).

*Limestone Slate:* Limestone with true cleavage structure. This is a somewhat rare phenomenon, but has been noticed in the Devonian limestone of Ilfracombe, which contains eyes of uncrushed calcite.

*Fissile Limestone:* Certain limestones which split into thin slabs along their bedding planes, and much used locally for roofing—*e.g.*, Stonesfield slate (Great Oolite of Oxfordshire), Collyweston slate (Inferior Oolite of Stamford), Duston slate (Northampton sands). These pseudo-slates have no true cleavage planes, and are, therefore, wrongly called slates, instead of tile-stone.

*Calcareous Rocks as Building Stones*.—The natural joint planes of limestone rocks determine the size of the blocks which can be quarried. In some cases the rock is so shattered by joints that it is useless as a building stone, while some statuary marbles can be worked in blocks up to forty tons in weight. The character of the stone varies considerably with the nature of the overburden. Under clay it is generally sound throughout, but when outcropping at the surface, or beneath a porous cover, the top is usually rubble, and much shattered stone occurs before the sounder beds are reached. The porosity of most limestones causes the fresh-quarried stones to be full of quarry water, rendering them soft and easily worked, but increasing their liability to injury by frosts when in this state. The more compact and crystalline varieties, however, are not so absorbent.

The adaptability of limestone to various architectural uses depends chiefly upon its structure, colour, and capability of taking a polish. Oolitic varieties, such as Bath stone, and the subcrystalline dolomitic limestones, cannot be worked as marbles, but nevertheless possess all the properties of a useful building stone. The beauty of many of the polished marbles depends upon the nature of the colouring matter and its disposition in streaks and veins through the stone. This peculiarity is the result of the colouring matter depending upon local impurities in the rock, forming seams in the bedding planes, instead of being evenly distributed by infiltration of iron compounds, as in the case of most sandstones. Thus pure limestone is white, as seen in statuary marbles; but even the famous Carrara marble is often coloured and veined. One very beautiful variety, called "peacock" marble, has a cream ground, with veins of scarlet, violet, or purple. The black and grey marbles owe their colour to carbon, magnetite, or highly ferriferous silicates. The green varieties may be coloured by ferro-magnesian

silicates, or by copper carbonate, while the red, yellow, and brown colours are caused by iron oxides of various degrees of oxidation. The well-known Connemara marble is a highly metamorphosed dolomitic limestone, in which the white calcite or dolomite is interlaced with twisted bands of green serpentine.

The weathering of limestones and marble is due chiefly to the well-understood action of carbonated waters upon calcium carbonate, whereby a soluble bicarbonate of lime is produced. Thus:—

$$CaCO_3 + H_2O + CO_2 = Ca\,H_2\,(CO_3)_2.$$

Superficial solution, therefore, readily takes place from the action of meteoric waters flowing over the surface, or filtering into the crevices of the rock.

Geikie has studied the course of weathering upon marble tombstones, and has established three phases of disintegration:—

(1) *Superficial solution* by the acids of the atmosphere, causing a loss of polish, and a roughening of the surface, with the formation of minute rifts.

(2) *Internal disintegration*, preceded by the formation of a superficial coating of calcium sulphate, which gradually breaks away, with a crumbling of the subjacent granules. The rapidity of disintegration from this cause varies greatly in different localities in proportion to the purity of the atmosphere. In large towns, where sulphuric acid is a common atmospheric impurity, the rapidity of weathering is increased, as may often be seen by the cement joints of limestone masonry standing out in bold relief.

(3) *Curvature and fracture*, a feature specially noticeable in thin slabs of marble set in sandstone frames, owing to unequal expansion on freezing of the absorbed water.

Coarse fossiliferous limestones are exceptionally bad for outside work, since the fossils and the matrix weather unequally, soon leaving the fossils in bold relief. Other included fragments may also cause unequal weathering. Thus, the small white tremolite crystals in some American marbles leave a pitted surface by weathering out; in verde antique marbles the calcite disappears faster than the serpentine; mica, talc, and veins of other minerals, while conferring beauty on the stone, are also subject to this objection. The best stones, therefore, are those which are least absorbent, and so uniform in texture that even weathering is secured. This condition is rarely found except in the most highly metamorphosed varieties.

Dolomites are far more durable than limestones, especially when the stone is made up exclusively of rhomboids of dolomite without any intervening calcite. The carbonates of lime and magnesia should be present in nearly equal proportions. Most magnesian limestones, however, contain both dolomite and calcite, which weather unequally, producing a rough surface from the more rapid solution of the calcite crystals. Some dolomitic limestones for this reason develop a cavernous structure. In many cases it is difficult to distinguish dolomite from calcite, even in a microscopic examination; but the more frequent rhombohedral outlines and yellowish tint of dolomite is sometimes conspicuous by the side of the colourless calcite granules with their more strongly-marked cleavage and lamellar twinning. Dolomite can also be distinguished from calcite by its insolubility in acetic acid. In some cases the durability of a limestone is increased by its partial silicification. This replacement of carbonate of lime by silica may even extend so far as to result in the formation of chert, as in some of the Portland beds, and the oolitic cherts of Yorkshire.

Limestones are not suitable for submerged marine structures, especially near high-water mark, on account of their easy perforation by molluscs. Devonian limestone from Plymouth, used in the construction of the breakwater, was so perforated by *pholas* that granite had to be substituted.

*Onyx Marbles.*—Certain calcareous rocks, such as travertine, deposited from calcareous springs, and stalagmites, or cave deposits, are of purely chemical origin, and differ materially from the metamorphosed sediments described above. These marbles are often miscalled alabaster, a term which should be confined to the massive compact form of gypsum. The name onyx refers to the characteristic banded and translucent appearance of these rocks when polished, a character which results from the more or less parallel lines of growth by successive depositions on the surface. The travertines are usually more translucent, more finely crystalline, and more delicately banded than the stalagmites. They are all of comparatively recent geological age, and their distribution appears to be limited to certain regions of recent volcanic activity, such as Arizona, California, Mexico, and Algeria. The stone is generally found only in thin layers, separated by porous, cellular bands of useless rock. The beautifully variegated colours are due to the oxidation of the small trace of carbonate of iron present in the deposit, various shades of colouring arising from the irregular oxidation effected by percolating water.

These onyx marbles were much used by the ancient Egyptians and Romans for small ornamental articles, sepulchral decoration, and ornamental slabs, and Algerian onyx is now extensively used in France for internal decoration. It is not suitable for external work, as it weathers badly, the dark bands gradually standing out in bold relief, and the clearer layers becoming opaque

and chalky. The requisites for a good onyx marble are as follows:—

1. Homogeneity of texture and absence of visible crystalline structure.

2. Freedom from cracks and porosity.

3. Translucency and a deceptive appearance of depth.

4. Beauty of colouring.

5. Ability to yield slabs of not less than an inch in thickness and a square foot in area.

*British Marbles and Limestones.*—The *Tertiary* limestones of Britain are unimportant, although much of the architectural beauty of Brussels and Paris is due to limestones of this age, and the Eocene nummulitic limestone has been extensively used from the remote time of the building of the pyramids.

*Cretaceous Limestones* are rarely adapted for building purposes. The middle chalk of Beer has been used locally in Devonshire; and the Totternhoe stone, a sandy limestone from the Lower Chalk, near Dunstable, is also sufficiently hard for this purpose. The Kentish Rag, a siliceous limestone in the Hythe beds, has furnished the stone for many churches and castles in Kent, and some thin bands of freshwater limestone in the Wealden beds, mainly composed of the shells of Paludina, form the well-known Sussex marble.

The *Jurassic* rocks yield many important limestones. The Purbeck marble closely resembles the Sussex marble, and was once extensively quarried for internal decoration. The Portland stone is a white, shelly, oolitic freestone, which ranks amongst the best in England. It varies considerably in structure and hardness, many of the earlier quarries, from which exceptionally durable stone was obtained, being now abandoned for the more easily worked beds. The Lower Oolite also affords many well-known freestones and ragstones, but the character of the rocks varies considerably in different localities, the best

beds thinning out rapidly into inferior seams. The best known quarries are those of Bath, Box, Corsham, and Minchinhampton, in the Great Oolite, and those of Ham Hill, Ketton and Ancaster, in the Inferior Oolite. The tile-stones, known as Stonesfield Slate, Collyweston Slate, and Duston Slate have already been alluded to.

The *Liassic* limestones are more or less argillaceous, and are valued more for the manufacture of hydraulic cement than for building stone. The Cotham landscape marble, occurring in the *Rhætic* beds, near Bristol, owes its arborescent markings either to the infiltration of oxides of iron and manganese before the soft calcareous mud was consolidated, or to the presence of carbon.

The *Permian* formation yields the important beds of magnesian limestone or dolomite, famous on account of their selection for the construction of the Houses of Parliament. Although, when well selected, these limestones are exceedingly durable, they do not appear to be well adapted for use in the smoky atmosphere of large cities. The most important quarries are those of Tadcaster, Bolsover, and Mansfield.

The *Carboniferous Limestone* is the chief source of British marbles, of which those of Derbyshire, Staffordshire and Bristol are largely used for decorative purposes, presenting a large variety both in colour and "figure," from the diversity of their fossil contents. In Ireland, also, many well-known marbles and limestones, which are often dolomitic, are quarried in this formation, such as the "shelly black" marble of Kilkenny, the red marbles of Limerick, Cork and Clare, and the white marbles of Connemara and Donegal, which, however, are spoilt for statuary purposes by streaks in the bedding planes in the former locality, and by coarseness of grain in the latter. A sienna marble is quarried in King's County.

*Devonian* marbles, such as those of Babbacombe, are

often built up of fossil corals, and are hence known as madrepore marbles.

*Archæan* marbles are highly metamorphosed. The famous "Irish Green" of Ballinahinch in Galway is a serpentinous limestone or ophicalcite resembling the *verde antico* of Italy; and the pink Tiree marble of the Hebrides contains porphyritic crystals of a dark green augitic mineral.

### SLATES.

The passage from indurated clay into slate has been accomplished by lateral pressure, accompanied in most cases by more or less chemical change, resulting in the development of new minerals. The history of a slate, therefore, commences with the fine muddy deposit accumulated on ancient sea-beds, and forming nearly horizontal layers of varying composition and texture. Subsequent earth movements, however, have completely metamorphosed these muddy sediments, the only trace of the original bedding planes being seen in the *stripe* or *ribbons*, running in bands of colour across the cleaved surfaces of the slate (Fig. 126). The direction of the stripe is usually at an angle with, and often nearly perpendicular to the cleavage planes, proving that the fissile structure of the slate is quite independent of the original planes of bedding. The experiments of Sorby, Daubrée, and Tyndall, prove conclusively that the fissility of slates is the result of lateral pressure, causing an elongation of the particles in a direction at right angles to that in which the pressure acted. (Fig. 127). A platy structure is developed in many other substances by hammering or rolling, but the development of true cleavage planes only takes place in fine grained rocks of particular composition and texture. As the economic value of a slate depends entirely upon the perfection of its fissile structure, it is important to bear in mind that the perfect development of this structure is often hindered,

as already shown in Chapter XI., by a variation in the composition of the original sediment, causing non-fissile, crimped or curly patches, and consequently a large amount of waste in quarrying. The perfection of cleavage is reached in some Welsh slates, which can be made to yield as many as forty slates from a single block of $2\frac{1}{2}$

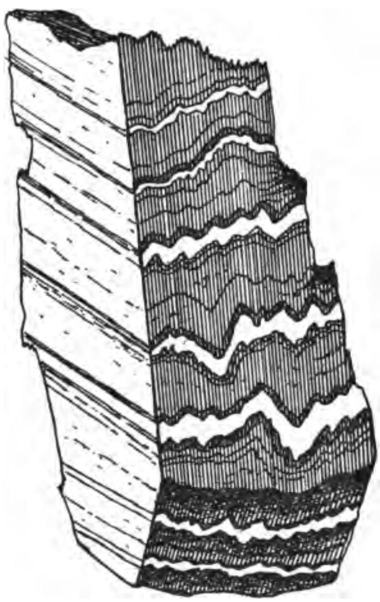

FIG. 126.—A BLOCK OF STRIPED SLATE,
Showing the relation of cleavage to the direction of pressure which has puckered the layers represented by the stripe.

inch thickness. Such a result is only possible in a fine grained sediment of uniform composition. Imperfections in slate cleavage may originate in several ways. Thus a *post* is a term given to a harder bed, either unaffected by cleavage or only cleaved to a limited extent; a *bend* is a change in the direction of cleavage on

passing into a coarser layer; a *cramp* is a sudden disappearance of cleavage owing to want of uniformity in composition of the sediment; a *curl* is a wavy cleavage

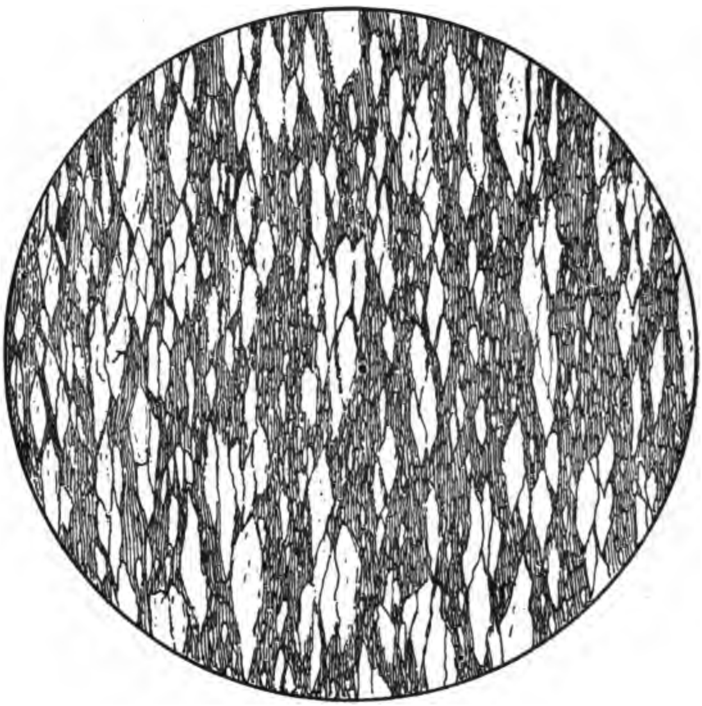

FIG. 127.—MICROSCOPIC SECTION OF A SLATE,
Showing the elongation of the particles in a direction at right angles to the pressure.

plane, caused by bands of varying texture. *Sparry veins* or ramifying veins of quartz often spoil the slate, and igneous dykes are liable to destroy the cleavage planes in their neighbourhood. Multiplicity of joints, also, may prevent large pieces of slate from being

obtained, a result which may also follow from double cleavage, caused by a secondary cleavage developed by subsequent disturbances of the rock. Thus some of the slates near Keswick split naturally into small pencil-like

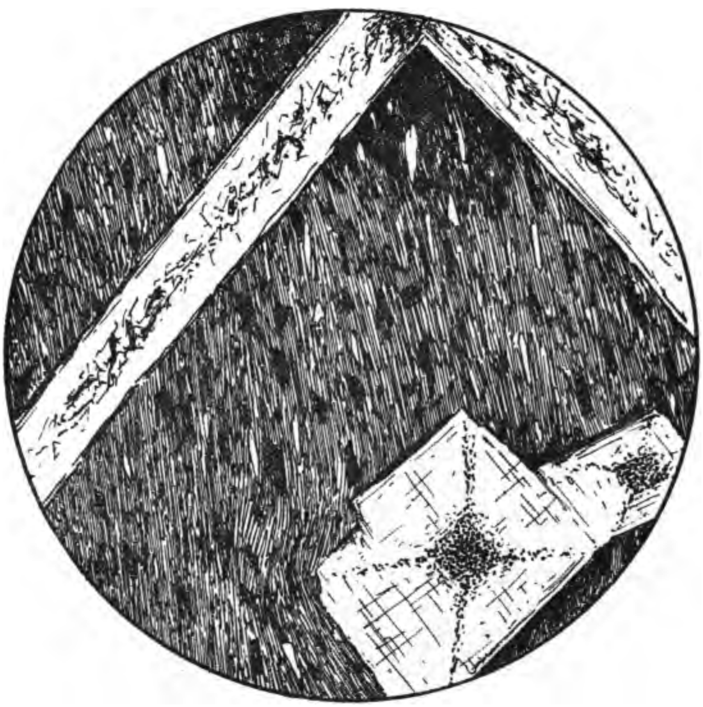

FIG. 128.—CHIASTOLITE SLATE.
The sections of chiastolite crystals showing the characteristic inclusions, symmetrically arranged.

fragments, owing to the existence of double cleavage, and are consequently only valued for the production of slate pencils. Bands of *alum slate*, rich in pyrites and giving by oxidation an efflorescence of alum, sometimes traverse a clay-slate region.

In a perfect slate a great deal of chemical metamorphism has taken place, much of the original silicate of alumina having been changed into minute elongated crystals of chiasolite, or mica, separated by opaque matter. The constituents are often difficult to identify, although some of the original detrital elements may sometimes be seen under the microscope to consist of quartz fragments, and less frequently felspars, mica scales and zircon crystals; biotites, if present, are generally decomposed into yellow spots of epidote. There is also oxide of iron (limonite), pyrites (probably formed in the original mud by the action of decomposing organic matter), and carbonaceous matter. The paste is often full of needles of rutile, "clay-slate needles," appearing either as opaque lines or as transparent crystals. The effects of contact metamorphism are seen in the still further development of secondary minerals, such as chiastolite, which often occurs in large crystals forming *chiastolite slate* (Fig. 128). Mica flakes also tend to increase in number, the slate then becoming glossy and passing into a *phyllite*; and, finally, when the cleavage planes are quite obliterated by the excessive development of mica into *mica-schist*. Similarly, *staurolite* slate, *ottrelite* slate and *dipyre* slate are produced by the development of these minerals respectively.

The colours of slates vary from black, grey, blue, and purple to green, according to the presence of various colouring matters, such as carbonaceous matter, sulphides and proto-salts of iron, manganese compounds, and ferro-magnesian products. Spots and blotches may be caused by concretions lying in the original planes of bedding, the original spherical shape having become ellipsoidal by compression. Hard particles, such as pyrites or magnetite crystals, also produce "eyes" by the resistance which they have offered to the movement of the compressed particles (Fig. 129). Fossils, when

present, also show more or less distortion from pressure.

Good roofing slates are not common. They should be of fine and even texture, hard, non-absorptive, and

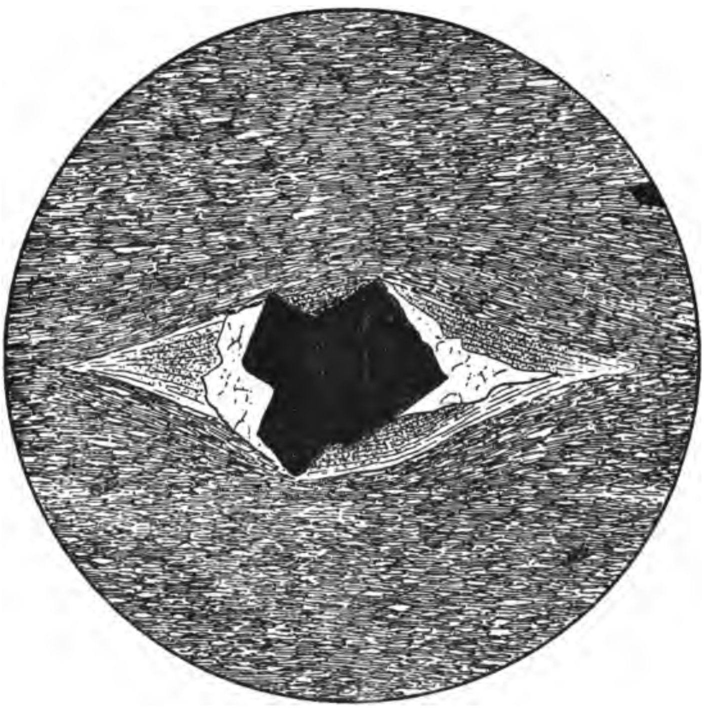

FIG. 129.—SLATE SHOWING AN "EYE," PRODUCED BY A CRYSTAL OF MAGNETITE.

The corners of the eye are occupied by secondary chlorite and quartz.

should emit a clear ringing sound when struck; they should split into regular slabs of moderate thinness, possessing a uniform colour and freedom from pyrites, and calcareous concretions. Pyrites in the form of

mundic, however, does not appear to effect the durability of the slate, crystals of this mineral in Ballachulish slates showing no sign of decomposition after an exposure of a hundred years in the atmosphere of Glasgow. Absorptive slates are liable to flake during frost, and some soft slates, such as the Devonian slates of Delabole, become harder on exposure. Slates unfit for roofing purposes may often be cut with a circular saw into slabs for cisterns, mantel-pieces, flooring, and other purposes.

The distribution of British slates is limited to the older Palæozoic formations; but, in California, slates of Cretaceous age are found, while Mesozoic slates occur in the Pyrenees and Alps. *Archæan* slates are quarried in Charnwood Forest, at Groby and Swithland.

*Cambrian* slates, generally green and purple, are amongst the best roofing slates in the world, and are largely worked at Penrhyn and Llanberis.

*Ordovician* slates are quarried at Festiniog. The "green slates" of the Borrowdale series of the Lake District are remarkable as having been originally a volcanic ash. The cleavage is often imperfect, especially in the coarser beds, and the slates are more variable in quality than those produced from muddy sediments. Slates of good quality are also procured in the metamorphosed rocks of the Highlands at Ballachulish, as well as in Ireland at Killaloe and elsewhere.

*Silurian* rocks yield slates at Llangollen, where slabs of an unusually large size are procured.

The *Devonian* strata contain many slaty beds, but the quarries of Delabole, near Tintagel, are the only important locality for good roofing slate. In Ireland the Valencia slates are of this age, but of inferior quality.

*Carboniferous* rocks yield a few slates of fair quality in Ireland at Clonakilty and Kinsale.

*Laterite.*—With the exception of slate, few of the argillaceous rocks form building stones. A highly

ferruginous clay, however, called *laterite*, soft when freshly dug, hardens on exposure to the air, and forms a durable stone, which is extensively used in India. It is generally brick-red in colour, and contains an abundance of concretionary nodules of pisolitic iron ore. On the Deccan plateau large deposits of this rock are found, sometimes between 100 and 200 feet in thickness. It is probably the result of the decomposition of basalts in moist tropical climates, aided by the organic acids of decaying vegetation. In this case it may be looked upon as originating from basic igneous rocks, rich in iron compounds, in much the same way as kaolin is produced from granite rocks.

*Tests for Building Stones.*—In all kinds of building stone there is often a great variation both in texture and composition, even in the same bed of rock. This uncertainty seriously depreciates the value of any tests to which a single small sample may be subjected. For example, the homogeneity of an apparently sound block of stone may be suddenly interrupted by concretionary and secretionary products, resulting either from the deposition of soluble minerals from percolating water or from the concentration of mineral substances originally disseminated throughout the rock. *Concretions* are aggregations formed in this way around a central nucleus, whilst *secretions* are the result of the infilling of pre-existing cavities by the gradual deposition of mineral matter upon the walls. In either case the result is the formation of a lump, differing in composition from the bulk of the rock in which it occurs. Most frequently the minerals composing these lumps are either calcite, siderite, pyrite, marcasite, or silica, and their occurrence in dressing a block of stone is objectionable, owing to their difference in hardness, colour or durability from the rest of the block. Not only nodular lumps, but also veins and streaks, often of microscopic size, may seriously influence the

value of a building stone. This local variation is not confined to the deposition of minerals; it may also result from the removal of portions of the rock substance, causing soft spots, which completely ruin the value of the block which it affects. The results of all building stone tests must necessarily be greatly influenced by the occurrence of these phenomena, from which scarcely any stone is free, although their presence is more prevalent in the porous limestones and sandstones.

In testing building stones four chief points must be considered—viz.: (1) The resistance which the rock opposes to the chemical action of the atmosphere; (2) its resistance to temperature changes; (3) its resistance to abrasive action both of wind and artificial friction; (4) its crushing strength and elasticity. In estimating the above qualities the first place must undoubtedly be given to a careful consideration of the way in which the rock weathers in the quarry, and its durability in old buildings in which it is known to have been used. This may be called the *Field Examination*. Of laboratory tests the following may be mentioned:—

(1) *Bulk Analysis*.—Chemical analyses may afford useful information as to the character of a rock when combined with other tests; but alone it is almost useless, except so far as it gives an approximate idea of its mineralogical composition and proportion of soluble carbonates.

(2) *Microscopic Examination*.—This should invariably supplement the above test, since it is the only ready means of determining the nature and durability of the component minerals, the structure of the rock, and the permanency of the colouring matter. Even this test is often inconclusive—as, for instance, in the determination of dolomitisation of limestone, and the nature of the felspar which may be present.

(3) *Micro-Chemical Tests.*—For this purpose the thin slice must be mounted without a cover glass. During grinding and polishing the order in which the separate minerals take a polish should be noted. The polished slice is then etched with strong hydrochloric acid, and the decomposed minerals noted. The etched specimen may then be stained with a coal-tar dye, such as malachite green, whereby many minerals are brought out into strong relief, and the structure of the matrix rendered more prominent. The nature of the felspars, the presence of dolomite, and other minerals, can also be determined by special tests, for which reference should be made to the text-books dealing with this subject.*

(4) *Absorptive Power.*—This important property can be ascertained by immersing a block of stone in water and noting the increase of weight. The value of a building stone is generally inversely as its porosity, which should not exceed 15 per cent.

(5) *Resistance to Disintegration by Frost.*—Brard's process is now obsolete. It consisted in boiling a cube of the sample to be tested repeatedly in a saturated solution of sodium sulphate, the loss of weight on drying being ascertained. A better plan is to freeze artificially small samples of the stone after immersion in water.

(6) *Determination of Specific Gravity.*—Although the density of a building stone is necessary to be known, it is no guide to durability, which depends rather upon the tenacity of adherence of the constituent minerals than upon their hardness or weight.

(7) *Compressive Strength.*—This test is usually applied by crushing one-inch or two-inch cubes between steel

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* See Behren's "Micro-Chemical Analysis" (Macmillan).

plates. The cubes should be carefully cut by sawing or grinding, and not by hammering, whereby the adherence of the mineral components may be weakened.

(8) *Elasticity and Rupturing Force.*—Bars of one-inch square section should be used. This test, however, has been but seldom employed.

(9) *Abrasive Resistance.*—The artificial sand-blast affords a convenient means of determining the resistance of a rock to the action of wind-blown sand.

(10) *Resistance to Carbonic Acid.*—Calcareous rocks, and rocks with ferruginous or calcareous cements, may be tested by immersion in water saturated with a bubbling stream of carbonic acid gas, the loss in weight being afterwards estimated.

The exceptional durability of the stones used in many old buildings is due to the fact that they were quarried near the outcrop, where there was no protective cover, and where the bad stone had been, to a large extent, weathered out by natural processes. Recently, attempts have been made to increase the durability of porous and calcareous building stones by painting them with a protective coat of soluble silicate, or preferably fluosilicate, by which the calcium carbonate is superficially altered into calcium fluoride, and silica is deposited in the pores.

# CHAPTER XIII.

## ROCKS USED IN THE ARTS AND MANUFACTURES.

*Various uses of Rocks—Lithographic Stone—Lime, Mortar and Cement—Brick and Pottery Clays—Refractory Substances—Sands—Grinding, Polishing and Cutting Materials—Pigments—Gems, natural and artificial—Artificial Stone.*

*Various Uses of Rocks.*—Many rocks, which are unsuitable for use as building stone, can still be employed in various manufacturing industries. Even overburdens and quarry waste are not, therefore, in all cases to be discarded as valueless. Some building stones are indeed often more profitably employed for other purposes. Thus many of the limestones of the North of England are more often burnt for lime, or used as flux in smelting furnaces, than quarried for building purposes; dolomite rocks are largely employed on the Tyne in the manufacture of magnesium salts, and magnesium limestone has also found a profitable use for the basic bricks required for lining Bessemer converters in the Gilchrist process of dephosphorising iron. The concretionary nodules, so common in these rocks, contain but little magnesia, and must be carefully avoided. Impure limestones may prove to be valuable cement stones, or, as in the case of the Wenlock limestone "ballstones," may yield concretions of purer material suitable for use as a flux in iron smelting.

In pointing out some of the more important industries in which rock materials of various kinds are employed, it must be borne in mind that new processes are continually springing up, necessitating the use of substances which might otherwise be discarded as waste. At the same time, old methods sometimes drop out of use in favour of newer discoveries. A noticeable instance of

this is afforded by the alum shale industry, the so-called alum shales of the Upper Lias, once extensively worked, being now entirely abandoned in favour of the more economical method of preparing alum salts by treating the carbonaceous shales of the coal measures with sulphuric acid.

There is little doubt that a considerable amount of the raw material which is annually imported into this and other countries for manufacturing purposes, might equally well be quarried at home, if only their requisite qualities were properly known and existing prejudices overcome.

*Lithographic Stone.*—Good lithographic limestones are rare, owing to the difficulty in finding the requisite combination of qualities. The famous Solenhofen stone, quarried near Munich, and at Pappenheim, on the Danube, is a fine-grained argillaceous limestone of a grey or cream colour, and of a compact and homogeneous texture. Freedom from flaws, veins and spots of foreign matter, is absolutely essential, and the rock must not be too thinly bedded, nor intersected by such numerous joint planes that large-sized blocks cannot be obtained. Highly metamorphosed limestones, even when pure, are too hard and splintery for this purpose, and the presence of silica is objectionable, on account of the increased difficulty of dressing and polishing the blocks. The most promising limestones are found in Mesozoic strata, and, in England, the Sun Bed of Temple Cloud, near Clutton, in the Rhœtic formation, the Wilmcote Stone, Hasler Stone, and Keinton Stone, of Liassic age, have all been tried for lithographic purposes with more or less success. Several limestones in India and America also bear a close resemblance to the Bavarian stone, but not one has yet been found equal in quality to the last named.

An attempt has been made to make artificial litho-

graphic limestone by rapidly hardening cement in thin slabs, which are then repeatedly moistened and heated until they shrink in bulk. They are then ground, mixed with fresh cement, and compressed in a mould under a pressure of 20 atmospheres. The air is then exhausted, and water is admitted, when the resulting stone is said to be superior to that of Solenhofen.

*Lime, Mortar and Cement.*—The quality of lime depends greatly upon the composition of the limestone from which it is made, whence the distinction between *fat* limes made from pure calcium carbonate, and *poor* limes made from impure limestones. Magnesian limestones are almost useless for lime-burning, the presence of even 10 per cent. of magnesium carbonate rendering the lime poor, and above 20 per cent. making it suitable only for slow-setting mortars.

(1.) Air-setting mortars are best made from limestones which are free from silica, iron or alumina, the presence of which is liable to cause slagging and sintering of the lime if too quickly burnt. For this reason the cherty beds of the carboniferous limestone, and some oolitic limestones are not well suited for lime-burning.

The best test for good lime is its behaviour on slaking. The more rapidly and completely it falls to powder the better is the lime. Lime which slakes slowly and unequally makes a mortar which does not cohere, and is liable to blister when used for plastering. The setting properties of mortar are also dependent upon the quality of the sand with which the lime is mixed for the purpose of preventing shrinkage and facilitating the access of carbonic acid, which is gradually absorbed by the mortar with formation of calcium carbonate. The sand should be clean and sharp. The presence of clay prevents the sand from adhering properly to the lime, and so diminishes the cohesion of the mass. The examination of ancient mortars shows that their excessive hardness

is due to the slow formation of a certain proportion of silicate of lime, in which case the sand would appear to exert more than a mere mechanical influence.

(2). Hydraulic lime is a poor lime, which falls slowly to powder when slaked. It is made from limestone containing silicate of alumina and iron oxide in suitable proportions. Fat limes may be rendered hydraulic by the addition of clay and iron oxide, by which means most of

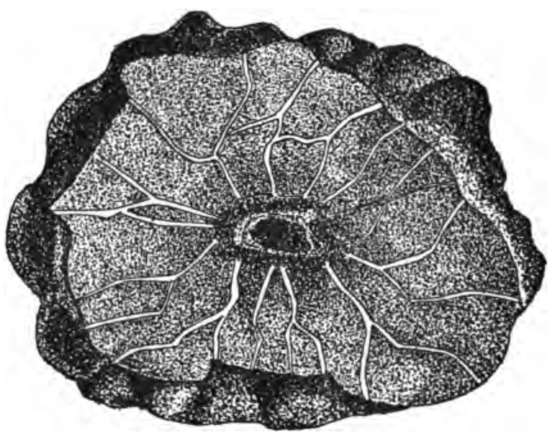


FIG. 130.—SEPTARIA NODULE,
Cut to show the calcite veins radiating from a central nucleus.
The matrix is argillaceous limestone.

the artificial hydraulic cements are made. Thus Portland cement is a mixture of chalk or marl and clay, burnt at a high temperature. River mud is also used instead of clay, and various other substances, such as puzzolana, trass, santorin earth, ochreous sand, argillaceous sandstone, burnt schist and calcined basalt, when added to fat lime, produce the same result, the quality of the cement varying with the proportions of clay and lime present in the mixture.

Natural hydraulic cements are made by calcining argillaceous limestones at a moderate temperature. For this purpose many British limestones are eminently suitable, such as the dark blue Aymestry limestone of Sedgley, the cement stones found in thin seams in the calciferous sandstone of Scotland, and the argillaceous limestones of the Lower Lias.

Many concretionary nodules are also valued for this purpose. Some calcareous clay ironstones, such as "curl" or "cone-in-cone," found in the coal measures of Coalbrook Dale, are used; while the Mulgrave cement is made from nodules in the alum shales of the Upper Lias.

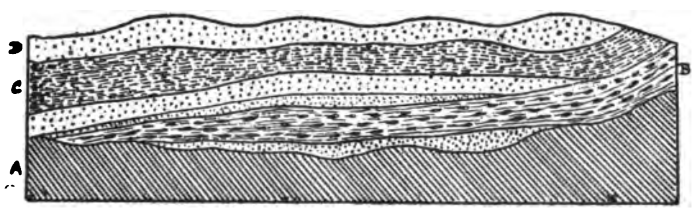



FIG. 131.—SEPTARIA IN THE OLIGOCENE STRATA BENEATH BERLIN. A, Old rocks; B, Septaria clay (middle oligocene); C, Lignite deposits (miocene); D, Drift.

Septarian nodules, or "turtle-stones," are natural cement stones of considerable value. These are concretionary nodules of argillaceous limestone, often containing a nucleus of organic matter, and penetrated by more or less radial cracks, which have become filled with crystalline calcite (Fig. 130). They occur in clay beds (see Figs. 131, 132), and are found in considerable quantity in the London Clay, Speeton Clay, Oxford Clay and Kimmeridge Clay. The London Clay septaria were once extensively dredged off Hants, Sheppey and Harwich, and large quantities from the Speeton Clay are now transported from Flamborough

Head to Hull for the manufacture of Roman or Parker's cement; but the septaria from the Oxford Clay and Kimmeridge Clay are too calcareous for use as cement stones.

In India, concretionary nodules of argillaceous carbonate of lime, occurring in the alluvial gravels, and called *kankar*, as well as deposits of calcareous tufa from mineral waters, are used for the manufacture of Portland cement.

The setting properties of hydraulic cement are due to chemical changes which are scarcely understood, but in

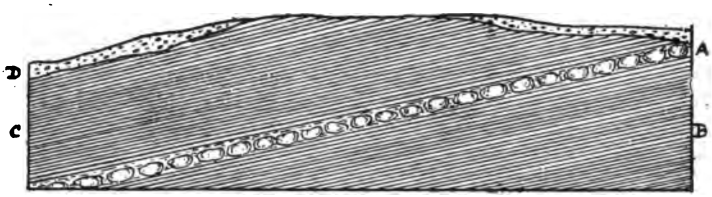



FIG. 132.—CEMENT BEDS, SPEETON CLAY.
A, Septaria, imbedded in light-coloured tenacious clay; B, Blue clay; C, Dark clay; D, Drift.

which the hydration of calcium silicates and aluminates seems to play an important part.

(3). Plaster of Paris forms the basis of certain cements such as Keene's, Parian and Martin's cements. Alabaster, the massive form of gypsum, from which plaster of Paris is made, is a hydrous sulphate of lime, of which the composition is represented by the formula $Ca\ SO_4 . 2H_2O$. When strongly heated, gypsum loses all its water and becomes anhydrite, which has no setting properties. In the manufacture of plaster of Paris, 5 per cent of the water must therefore be left in the calcined gypsum, a definite hydrate being formed with the composition $(Ca\ SO_4)_2 . 2H_2O$. The setting property of this substance is due to a recombination with water to form

the original hydrated gypsum. The mode of occurrence of gypsum in the New Red marls of Nottinghamshire is represented in Fig. 133, the nodules being excavated and the gypseous marl lying between them being left as supports to the excavations.

A
B
A
B
A
B

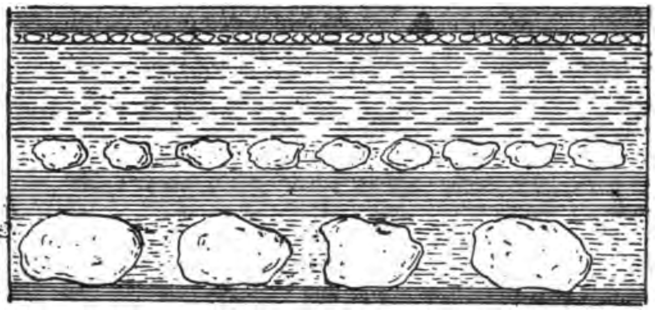


FIG. 133.—PLASTER OF PARIS WORKINGS IN NOTTINGHAMSHIRE.
A, Nodules of Gypsum, separated by gypseous marl;
B, New red marl.

The following table gives the composition of some natural and artificial cement stones, but there is considerable variation in the proportions in different samples.

| | Septaria from London Clay. | Argillaceous Limestone. | Ordinary Limestone. | Mixture of Limestone and Clay (Portland Cement.) |
|---|---|---|---|---|
| Lime .. .. | 35·84 | 37·6 | 50·15 | 28·14 |
| Silica .. .. | 17·75 | 18·34 | 4·46 | 32·83 |
| Alumina .. .. | 6·75 | 4·08 | 1·00 | 11·27 |
| Oxide of Iron .. | 7·0 | 3·41 | ·48 | 3·36 |
| Magnesia .. .. | ·5 | 1·39 | ·87 | ·86 |
| Alkalies .. .. | — | ·19 | — | 1·14 |
| Carbonic Acid .. | 28·16 | 31·05 | 40·40 | 21·5 |
| Water and Loss — | 4.0 | 3·94 | 2·64 | ·92 |

*Brick and Pottery Clays.*—Plastic clay is the basis of all fictile manufactures, from the coarsest brick to the finest variety of pottery. This plasticity, which nearly all the natural clays possess, depends upon the presence of combined water, and is destroyed by the expulsion of this water by heat. Occasionally, however, clays are met with which do not possess this property, but, instead, fall to pieces in water to an impalpable powder. These are known as *Fuller's Earth* clays, on account of their use for absorbing grease from wool. Ordinary plastic clays also possess detergent qualities, but owing to their plasticity are not so easily manipulated. The fulling property of Fuller's Earth clay seems, therefore, to be due rather to physical than to chemical peculiarities. Fuller's Earth occurs in the Lower Ludlow rocks, near Malvern, and in the Sandgate beds of Reigate and Maidstone; but the most important deposits are in the Lower Oolite of Midford, Woburn, and Nutfield, where it occurs as a greenish calcareous clay, in lenticular patches, in ordinary clay seams. It has a distinct soapy character, owing to the presence of a small quantity of magnesia. A small proportion of iron is often present in the state of protoxide, in which case it speedily weathers to a brownish yellow colour by oxidation. The use of this substance in woollen manufacture is now superseded by alkalies.

Returning to the plastic clays, these cannot be used alone for bricks or pottery, owing to their liability to crack in drying and to lose their shape in firing. It is, therefore, necessary to add some hardening aplastic material, such as sand or ground flint. Some pottery also requires the addition of a fusible material to impart translucency and density. Mixtures of these three materials, plastic clay, silica, and fusible matter, form the paste from which the various kinds of pottery are made. Thus bricks, tiles, and common stoneware

are made from mixtures of impure clay and sand, the fired products being opaque, hard, and coloured with the ferruginous impurities present in the clay. The better kinds of earthenware and stoneware are denser, and more or less free from colour, owing to the use of purer clays and sands, and the admixture of fusible material, such as felspar, china-stone, bone-ash, lime, gypsum, barytes, etc.; while the finer kinds of pottery are produced from the purest kaolin, with variable proportions of the above-named fusible substances. In all the better classes of pottery, the clays must be free from iron compounds and

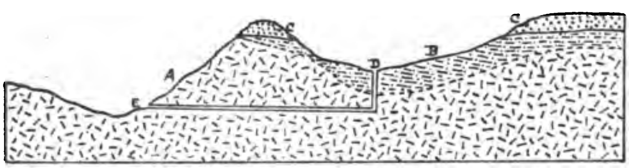



FIG. 134.—CHINA CLAY WORKING IN CORNWALL.
A, Granite; B, Decomposed Granite; C, Overburden; D, Top of Launder, into which falls the milky stream of kaolin and mica, washed out of B; E, Adit level from which the milky stream is led to the settling pits.

from silicates of lime, potash or soda, which would fuse in the furnace at too low a temperature, the added flux being fusible only with difficulty. According to the extent to which superficial melting takes place on firing, the products are either impervious, and, like stoneware, need no glazing, or a subsequent glaze must be imparted to prevent porosity, as in the case of majolica and porcelain ware.

The adaptability of a clay deposit for fictile purposes depends, therefore, upon its composition and purity. The purest variety, called *kaolin*, or china clay, is both washed out from decomposed granite and also dug from the valleys and hollows in the neighbourhood of the granite masses of Devon and Cornwall. (See Figs.

134, 135). The essential constituent of kaolin is the mineral *kaolinite*, a hydrated silicate of alumina, formed (as described in Chapter X.) from the decomposition of felspar. This substance is seen under the microscope to occur as thin, white, flexible and inelastic six-sided scales, often aggregated in bundles, and more or less plastic according to the size of the particles. Kaolin contains, besides these crystals of kaolinite, quartz grains and mica scales, which must be separated before it is used in the potteries. Other varieties of white clay, of slightly inferior purity, are also met with, such as the seams of *pipe-clay* in the Bovey beds of Devon-

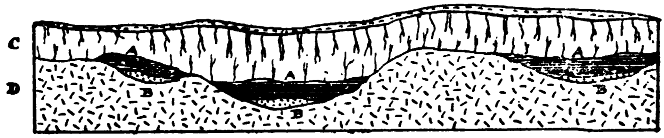



FIG. 135.—CHINA CLAY IN VEGETABLE CREEK, NEW SOUTH WALES, Preserved in ancient valleys beneath a lava stream.
A, China clay; B, Stanniferous alluvium; C, Basalt; D, Granite.

shire, and in the Lower Bagshot beds of Poole, Dorsetshire. This contains rather more silica than kaolin. Partly decomposed granite, called *china-stone*, containing quartz, altered orthoclase, mica and gilbertite, is also worked near St. Austell, for use in the potteries as a vitrefiable component of the paste; while in Ireland, at Belleek, red orthoclase itself is calcined and manufactured into porcelain, the iron separating during calcination in the metallic state, and being removed by magnets from the powdered milky clay. More often, however, clay deposits are impure, and contain more or less mica, quartz, undecomposed felspar, oxides of iron, calcium and magnesium, and organic matter.

The ultimate colour produced on burning impure

clays depends partly on the amount of iron present, partly on the temperature to which they are subjected, and partly on the presence or absence of reducing matter. Yellow clays contain hydrated sesquioxide of iron, and usually occur where red or grey clays have weathered. These, on ignition, become red, owing to the formation of anhydrous ferric oxide. Grey clays owe their colour usually to iron pyrites, and blue clays to ferrous carbonate; these also burn to a red colour owing to the formation of the anhydrous ferric oxide. The red colour is diminished in intensity by the presence of organic matter, which reduces the ferric oxide to the ferrous state. Lime and magnesia also reduce the amount of colour in the same way, and chalk is often added to a red burning clay to produce yellow bricks, a high temperature being used to effect the union of the iron with silica, to form a silicate of iron. Cream and buff bricks may also be made from clays containing less than 1½ per cent. of iron. A small amount of calcareous matter in a finely divided state is advantageous, diminishing contraction, and acting as a flux, whereby the grains are fused into a compact mass. Too much lime, magnesia or iron, however, causes bricks to "run"; while calcareous fossils and nodules spoil the bricks by causing them to "blow." Sand must always be added to stiff clays to lessen the liability to crack in drying. Loamy clays are, therefore, more suitable for bricks than stiff clays. Deposits of these loamy clays often occur amongst the superficial drifts, and are known as *brick-earth* (Fig. 136). All clays improve by exposure to the air and frost, whereby mechanical disintegration is promoted, together with the oxidation of pyrites.

A superficial glaze may be imparted to bricks and pottery by means of suitable fusible substances. Thus, Staffordshire blue bricks, made from dark red coal-measure clays, are sprinkled with dust of stone and iron

(iron swarf), by which means protosilicate of iron is produced on firing. Pottery glazes are obtained by firing with a superficial coating of some substance which will form a fusible silicate with the silica of the clay. Thus, tin-stone, orthoclase felspar, galena, or common salt, form a glassy coating of silicate of tin, potassium, lead or sodium.

*Refractory Substances.*—When a clay contains but a small proportion of iron, lime or alkaline silicates, it becomes a *fire-clay*. Such refractory clays, however, are not always pure hydrated silicate of alumina. The famous Stourbridge clay of the South Staffordshire coal-field contains about 64 per cent. of this substance, with 33 per cent. of finely divided silica, and 2 per cent. of ferric oxide. Other coal-measure fire-clays have been shown by Mr. W. M. Hutchings to consist chiefly of a matrix of finely divided secondary hydrated mica, in which fragments of quartz, felspar, muscovite and biotite occur. Most of the British fire-clays are derived from the under-clay of the coal-measures; a notable exception being the Wakerley clay, of Oolitic age, which is claimed to be superior in refractory power to that of Stourbridge. A good fire-clay should possess not only the property of infusibility, but also resistance to contraction on heating. The shrinkage is sometimes reduced by the addition of about $\frac{1}{8}$ part of powdered potsherds (grogg).

All fire-clays require to be weathered to promote disintegration; they are then ground, sifted and moulded, dried at a moderate temperature, and finally baked at a temperature gradually increasing to white heat. For the manufacture of crucibles, the clay is mixed with variable proportions of coke, graphite or sand.

Clay is not the only rock which yields valuable refractory material. The famous Dinas fire-bricks, used for lining furnaces, are made from a disintegrated sandstone

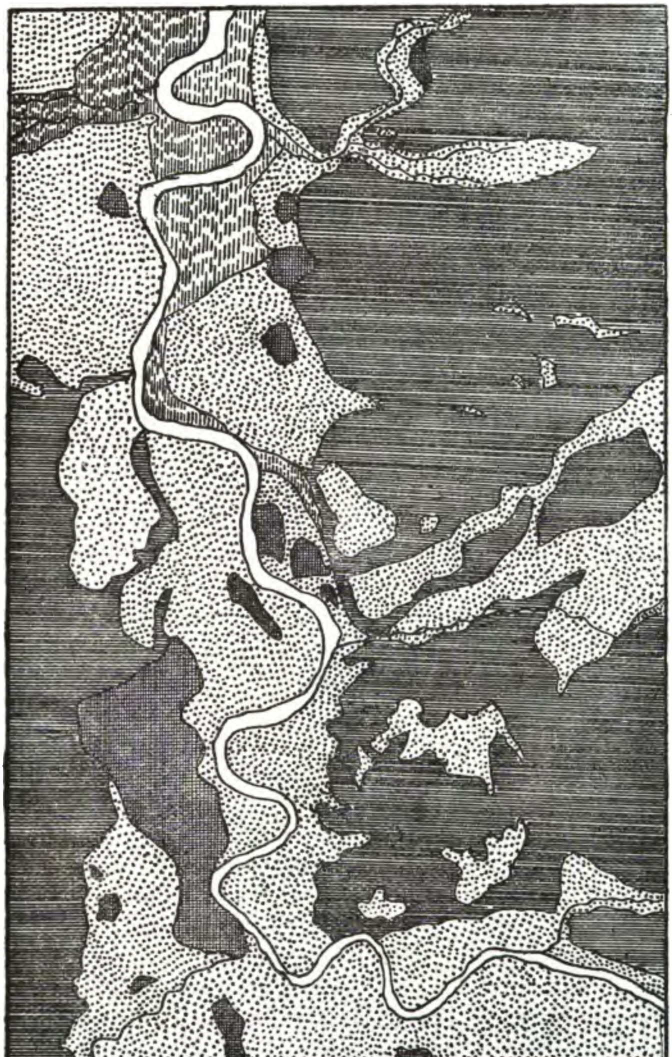


Fig. 136.—Brick-Earth Deposits in the Thames Valley, between Kingston and Woolwich. Vertical shading represents London clay; dotted shading, Gravel beds; horizontal dashes, Alluvium; reticulated shading, Brick-earth.

from the Millstone Grit of Glamorgan. They consist of 96 per cent. of silica with a small proportion of alumina, and oxides of iron, lime, magnesia, potash and soda. Gannister, also, a highly siliceous seat earth from the Yorkshire coal-measures, is made into bricks for lining Bessemer converters. The siliceous infusorial earth, known as diatom ooze, when mixed with lime and fire-clay, makes bricks of a highly refractory nature, and of extreme lightness, weighing only about one-sixth as much as the ordinary fire-bricks.

Other siliceous rocks, known as fire-stones, leckstones and pot-stones, are quarried for use as hearthstones and other refractory purposes, without further preparation. Of this nature are the Portland Burr stone, a soft sandy oolite; the Malm rock, or Reigate stone, quarried in the Upper Greensand of Surrey; and certain sandstones of the Old Red Sandstone and Carboniferous formations. The leckstones are old consolidated ash beds, formerly worked for fire-bricks, in Fife and Linlithgow. The firestone of Nevada is a light, porous siliceous rock, similarly employed, and easily sawn into blocks of any shape; while a rarer material is found in the quartz slate of Silesia, a soft, fibrous quartzite, containing 92 per cent. of silica.

Soapstone and asbestos have long been employed as refractory substances. The pot-stones of North Italy owe their infusibility to the presence of these substances, mixed with talc and chlorite. The use of asbestos for fire-proofing purposes has greatly increased in recent years, and large quantities are procured from the serpentine of Italy, Canada, and Gundagai, in New South Wales.

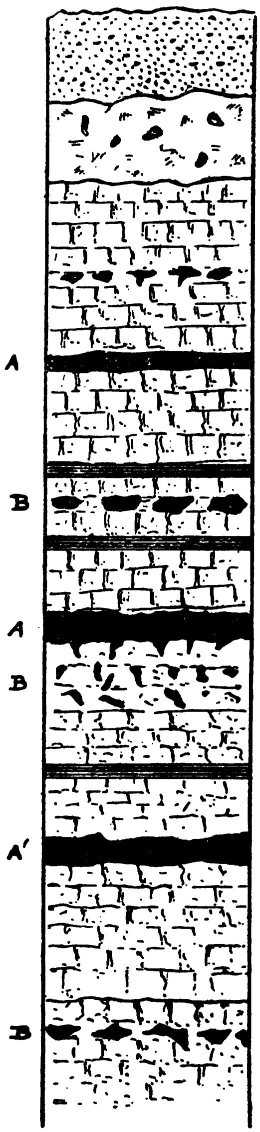
*Sands.*—The economic uses of sand vary considerably with the purity of the deposit as well as the nature of the grains. The following varieties of sand may be distinguished, viz., *virgin sands*, arising from rocks

actually undergoing disintegration, and generally intermixed with much clayey matter; *pit or quarry sands*, or the stratified sand formations, which are generally both clean and sharp; *river sands*, which may be also clean, although the grains may be more or less rounded; *sea sands*, from which it may be necessary to remove deliquescent salts by washing. For mortar, the sand should be clean, sharp, and moderately coarse: rounded grains make a brittle mortar, and the presence of clay prevents proper adhesion between the sand and the lime. Glass sands must especially be free from iron oxide, which would produce coloured silicates, and diminish the transparency and freedom from colour of the resulting glass. Foundry sands, on the other hand, give better results if they contain a small admixture of clay. The sands of Mansfield have been held in high esteem for the perfection of the finish which they give to castings.

Pure silver sands, free from iron, lime and clay, are by no means common, and a great deal has been imported from the coast of Holland. Probably some of the purer sandstones might be crushed for glass-making purposes. Calcined flints were once extensively used for this purpose, the term flint glass having been adopted in consequence of this fact. The chert beds in the Millstone Grit of Flintshire are quarried for use in the Staffordshire Potteries as a substitute for sand. At Brandon, in Suffolk, flints are still worked for the manufacture of gun-flints. (See Fig. 137).

*Grinding, Polishing and Cutting Materials.*—Good grindstones should be both hard and tough, with a keen bite and even texture. They should neither wear smooth nor contribute much earthy dust to the flour when used as millstones.

Some conglomerates were used for hand-mills or querns in pre-historic times, and Old Red Sandstone conglomerates are still in use as cyder millstones. Coal-




measure sandstones, when sufficiently fine grained, yield many well-known grindstones, such as those of Newcastle, Bilston, and Sheffield. Yorkshire grindstones are procured both from the Millstone Grit and Gannister beds, which, when hard and close-grained, are used as carpenter's millstones. The white quartzites of Norway and Scotland and Derbyshire chert have also been used for pottery grinding. Amongst rocks of more recent age, the Devonshire batts are scythe stones procured from the porous, fine-grained sandstone of Blackdown Hills, Cullompton, where they form concretions in the loose Upper Greensand formation; and the celebrated French *Burr Stones*, of tertiary age, owe such a value to their hardness and roughness, that even small fragments are pieced together to make blocks of the necessary size for millstones. Some millstones and polishing

FIG. 137.—FLINT MINING AT BRANDON, SUFFOLK. VERTICAL SECTION OF CHALK, Showing flint in nodules B and layers A. The chief bed is the "floorstone," A¹. Many of the nodules are "horned," the "horns" projecting into the next bed of chalk.

material are procured from the volcanic rocks. The "Dutch Blue Stones" are quarried near Andernach, from the Eifel lavas, and have maintained their reputation since Roman times; while the pumice of Lipari is largely used in the arts for polishing purposes. The

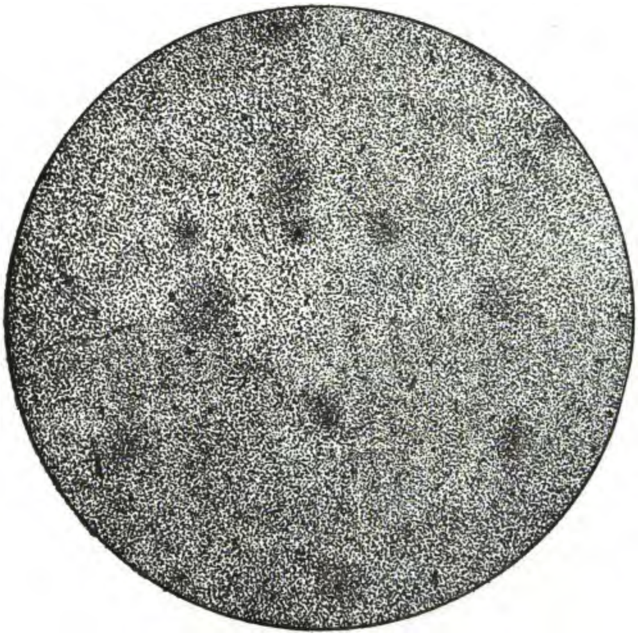


FIG. 138.—MICROSCOPIC SECTION OF A WHET-SLATE (AYRSHIRE).

finer grained stones, used as oil-stones for finishing after grinding, are variously named hone-slates, whet-slates (Fig. 138), or novaculites (razor-stones). Sometimes the slate rocks in the neighbourhood of an igneous dyke are sufficiently indurated to form a hone-stone, an example of which occurs in the slates of Hestercombe, in the neighbourhood of a syenitic dyke. Some fine-

grained compact slate rocks of this country almost rival the famous Turkey oil-stone of Asia Minor. Of this nature are the Charley Forest Stone, Idwal Stone, and the Cutler's Green, of Snowdon. The Belgian whet-slate was shown by Rénard to be full of microscopic

FIG. 139.—RADIOLARIAN CHERT,
Showing casts of radiolaria in a siliceous matrix darkened by carbonaceous and ferruginous matter.

garnet crystals. Even shales may yield beds of sufficient hardness for polishing purposes, the well-known Water-of-Ayr stone being of this nature; while the Lydian stone of Devon and Cornwall, used as a touchstone for gold, is an indurated, carbonaceous cherty shale of the culm measures. Much of this has been shown to be of

organic origin (see Fig. 139). The Norway ragstone, used as a coarse hone-stone, is a tough, highly siliceous mica schist, often characterised by a slight twist in the direction of its length.

The novaculites, represented typically by the oil-stones

FIG. 140.—ARKANSAS HONE-STONE (NOVACULITE).
Under crossed nicols, showing secondary silica in a fine-grained siliceous matrix.

of Washita and Arkansas, are fine siliceous rocks of somewhat obscure origin. Rutley believes that many of them are silicified dolomites; but the Arkansas novaculites have also been ascribed to the mechanical deposition of fine-grained quartz. They occur interstratified with Palæozoic shales and limestone in folded strata. Some

of the pure white varieties may be siliceous deposits from hot springs, while others are altered schists, in which case their abrasive property may be due to minute crystals, either of silica, garnet, or rutile. As seen in Fig. 140, some of the silica is of secondary origin.

Finely divided silica occurs naturally in several useful forms. *Rotten stone* is a light porous siliceous mass, resulting from the removal of calcareous matter from certain siliceous limestones, such as the flagstones of Dryrigg, Coniston, and some of the limestones of the Yoredale series. It contains alumina in addition to silica.

*Bath Brick* is manufactured from the fine siliceous silt of the River Parret, at Bridgwater, arising, according to Ansted, from the siliceous cases of infusoria destroyed by the salt water. *Tripoli* is a fine earthy silica, resulting from the frustules of diatoms, and forming the Kieselguhr, or flint-froth, of Germany, and the Berg-mahl, or mountain meal, of Sweden. In the Isle of Skye, Loch Quire contains a deposit of this substance, 25 feet thick, consisting of a greenish earth drying, when cut into blocks, into a white glistening floury substance. Similar deposits are found in Ireland in the Bann Valley, and near the Mourne Mountains. The well-known beds at Bilin, in Bohemia, largely made up of frustules of Gaillonella, have long been valued for polishing purposes; and in the United States a large area of Virginia is covered to a depth of 40 feet with a similar substance (Fig. 141). These microphytal earths in their purest form contain as much as 97 per cent. of silica in a fine mealy form, and have been extensively used, not only as abrasive material, but also in the manufacture of dynamite for the purpose of adding viscosity to nitroglycerine.

Amongst other substances valued for their hard-

ness, the chief are emery, corundum, agate and the diamond.

Emery and corundum are native forms of alumina. The so-called red emery is got by crushing the garnet rock of Norway. True emery is an impure variety of

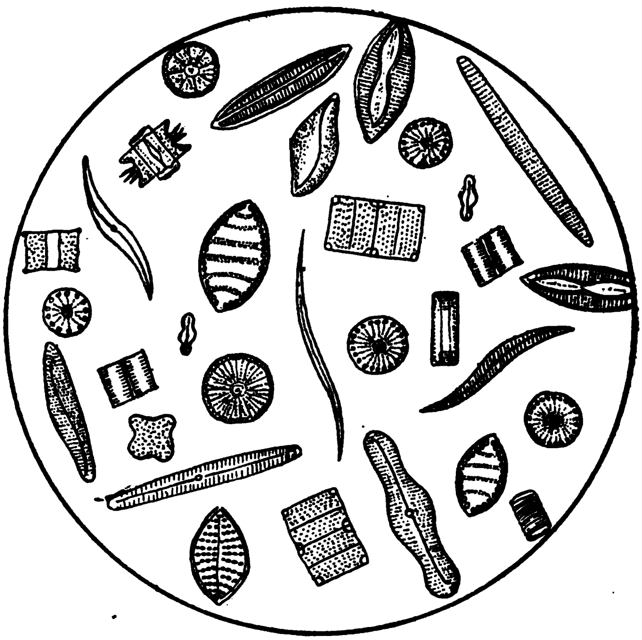


FIG. 141.—FRUSTULES OF DIATOMS FROM INFUSORIAL EARTH OR KIESELGUHR.

corundum mixed with magnetite, found in the limestone rocks, and in the overlying soil of Naxos and Asia Minor. Corundum occurs abundantly in the metamorphic rocks of Southern India, and at Corundum Hill, North Carolina, where it is quarried in large blocks and crushed for the market. This latter locality has a peculiar interest, inasmuch as the corundum is often

associated with the rarer crystalline coloured varieties, ruby and sapphire, in their original matrix of peridotite and hornblendic gneiss. The occurrence of the diamond has already been described in Chapter VII.

In connection with these substances, useful on account of their excessive hardness, agate may be mentioned. This substance, in addition to its use for ornamental articles, is employed for the knife-edges of balances, for burnishers, and for crushing hard minerals. Its occurrence is of geological interest, since it is most commonly formed by the deposition of secondary silica, in the cavities of basic igneous rocks, by successive layers of chalcedony, jasper, carnelian or quartz. The cavity is usually lined in the first place with a green coating of delessite, a hydrous silicate of aluminum, iron and magnesium, resulting from the decomposition of augite. When detached from the cavity, the agate usually retains this green coating, or its altered equivalent of red ferric hydrate. The waste of such amygdaloidal trap-rocks leads to the occurrence of agates in the river gravels, which explains their abundance in the Deccan and Uruguay. In Britain they are found in Forfar, Perth, and the Cheviots. The variety of colour and pattern, due to the presence of bands of various forms of silica and various mineral inclosures, give rise to the varieties known as Moss agate, Mocha stone, Fortification agate, onyx, etc. The centre of the agate-cutting industry is at Oberstein, in Germany, where the stones, imported from America, are not only cut and polished, but also artificially coloured by prolonged soaking in honey, which is then carbonised by sulphuric acid; the layers being unequally pervious, banded effects are produced, and by other colouring matters sardonyx and chrysoprase are artificially imitated.

*Pigments.*—Amongst the many mineral pigments a few only can be mentioned here, the most common

being the hydrated oxides of iron known as *ochre*, *umber*, *bole* and *reddle*. *Ochre* is usually found in the form of clay or sand coloured by iron oxide present to the extent of 15 or 20 per cent. It generally requires washing, although the presence of finely divided silica is not detrimental, but rather improves its adhesion and covering power when mixed with oil to form a paint. Good yellow ochre is found in the Lower Greensand of Shotover Hill, near Oxford, and in the cherty arenaceous beds of the Lower Lias and Rhœtic beds. Brown and red ochres are often associated with beds of iron ore.

*Umber* is a mixture of peroxides of iron and manganese, and is also a product of decomposition found in veins in crystalline schists and elsewhere. Some commercial umber is merely brown lignite finely pulverised, and may be at once detected by the action of heat. *Mars brown* is a pigment of a similar nature to umber, but with an orange tinge. *Bole* is a friable clay coloured yellowish or reddish brown by iron oxide, varieties of which are known as Sinopian earth, Bohemian earth, Lemnian earth, etc. In Antrim it occurs between the lava flows as a product of decomposition of basaltic rocks. *Reddle* is a deep red clay resulting from the decomposition of iron ores, and frequently associated with hæmatite deposits in Cumberland and the Forest of Dean.

Other pigments are furnished by minerals of quite a different class. Thus permanent white is produced from *cawk* or barytes, a common veinstone in the Cornish mines, and in the carboniferous limestone of Derbybyshire; while Bideford black is simply soft carbonaceous shale, or culm, ground to powder. Steatite and pipeclay are extensively used to mix with metallic and other pigments to give the necessary body for pastel colours and coloured chalks and crayons. The use of chalk for whiting scarcely needs allusion.

A rarer pigment is *lapis lazuli*, the source of ultramarine. This substance is an anhydrous silicate of aluminium and soda, with sodium sulphide and sulphate, occurring in crystalline limestone in Persia and Bokhara. Its value has been much depreciated by the manufacture of an artificial variety by heating together clay, sulphur and sodium carbonate, the resulting colour being almost equal to the natural ultramarine.

Many other rock substances are also used in the production of mineral colouring matters. *Chrome ochre* is a native green pigment consisting chiefly of oxides of chromium. *Malachite*, the green carbonate of copper, is also used in conjunction with white clayey earth, and a species of ochre, coloured by ferro-magnesian silicates forms *terra verte*, or green earth. Hæmatite is powdered to form *Indian red*, and the native peroxide of manganese produces the pigment known as *manganese brown*. *Antwerp brown* is prepared from native asphaltum or bitumen, and another brown, called *Vandyke brown*, is formed from *cappah*, a manganese peat. Somewhat similar native earths are used under the names of *Rubens*, *Cassel* and *Cologne brown*.

*Gems*: *Natural and Artificial*.—The extensive industry which has arisen from the manufacture of artificial gems renders necessary the following list of the more important natural stones, with a brief description of their chief peculiarity:—

1. *Carbon*:—

   The *diamond*. (See Chapter VII).

2. *Quartz*:—

   *Rock crystal*, often cut to represent diamond.

   *Flèches d'amour*, quartz containing slender prisms of rutile.

   *Cairngorm*, *False topaz*, yellow varieties of quartz.

   *Amethyst*, purple quartz, coloured by oxide of manganese.

*Aventurine*, quartz, spangled by scales of mica.

*Cat's eye*, quartz and ferric oxides, having a fibrous structure due to the presence of altered crocidolite.

*Chrysoprase*, green chalcedony, coloured by oxide of nickel.

*Carnelian*, red chalcedony, coloured by oxide of iron.

*Sard*, reddish-brown form of the above.

*Onyx*, alternating bands of light and dark coloured chalcedony.

*Sardonyx*, alternations of sard and white chalcedony.

*Heliotrope*, deep green chalcedony, with spots of red jasper,

*Mocha stone*, quartz with dendritic oxide of iron or manganese.

*Noble opal*, hydrated silica, with play of colours due either to microscopic striæ or to thin lamellæ of different refractive index.

3. *Alumina* :—

*Oriental ruby*, bright red variety of crystalline alumina, the colour being due to oxide of chromium.

*Sapphire*. blue transparent crystalline alumina.

*Oriental topaz*, a yellow variety of sapphire; the green variety is *oriental emerald*.

*Spinel ruby*, a compound of alumina, magnesia and iron.

*Chrysoberyl*, a compound of alumina and glucina; also called *oriental cat's eye*.

4. *Aluminium silicate* :—

*Emerald*, transparent green silicate of aluminium and glucinum.

*Aquamarine*, a paler variety of the above.

*Beryl*, a coarser variety of emerald.

*Topaz*, yellow and white varieties of silicate and silico-fluoride of aluminium.

5. *Zirconium silicate* :—

*Hyacinth* or *Jacinth*, a rich red transparent zircon.

*Jargoon*, a less brilliant variety of the above, distinguished from diamond by its high specific gravity (4·5) and inferior hardness.

6. *Double silicate of aluminium and iron :—*

*Garnet*, known as *carbuncle* when cut *en cabochon*.

*Cinnamon stone*, in which iron is replaced by calcium.

7. *Felspar :—*

*Labradorite*, the schiller and colour being due to diallage microliths.

*Moonstone*, an opalescent variety of adularia (transparent orthoclase).

*Amazon stone*, a green variety of microline.

*Sunstone*, an oligoclase having a reddish sheen from lamellæ of specular iron ore.

8. *Hornblende :—*

*Jade*, largely carved by Maories and Chinese; a green, tough, fibrous variety of hornblende, with interlacing fibres.

9. *Serpentine :—*

*Precious serpentine*, a translucent serpentine of oil-green tint.

10. *Aluminium phosphate :—*

*Turquoise*, a hydrous phosphate containing a trace of copper.

*Occidental turquoise* (odontolite), a fossil ivory coloured by phosphates of iron, and used as a substitute for the above.

The artificial imitation of the above gems depends in the first place upon the manufacture of a glassy paste of high lustre. Now the transparency and lustre of a glass depends upon the absence of crystalline structure and of colour, the former depending partly upon the rapidity of cooling, and partly upon the composition of the paste; while the latter depends upon the purity of the ingredients. If a flint glass is kept hot too long, devitrification sets in, a white fibrous product being the result. The substance known as Réaumur's porcelain is a devitrified glass of this nature. The glass used as the base of artificial gems is called *strass* or *paste*, and is usually composed of powdered rock crystal, potassium

carbonate, and a large proportion of red lead, which increases both its fusibility and lustre, while at the same time the small proportion of alkali diminishes the danger of devitrification. By the addition of various colouring matters—such as oxides of cobalt, chromium, manganese, gold and antimony—the different gems are imitated. Pastes of a different composition are also used. A few gems have been artificially prepared with the same composition and properties as the natural stones, but the results have more geological than commercial interest. The most successful of these efforts are the rubies obtained by Freny and Verneuil by carefully heating a mixture of barium fluoride and alumina with a trace of potassium bichromate, the addition of cobalt leading to the production of sapphires.

*Artificial Stone.*—The manufacture of artificial stone is an increasing industry, and promises an employment for a great deal of what is now regarded as quarry waste. The *scagliola* of Florentine art is an artificial stone made of fragments of marble consolidated by plaster of Paris and glue. Artificial sandstone is made in Belgium by heating under pressure a mixture of clean coarse sand with hydraulic cement; the resulting stone is at first soft, and can be cut with a knife, but it rapidly hardens so as to withstand a crushing pressure of 6,000 lbs. per square inch. Ransome's patent stone is made by cementing sand with soluble silica or water glass (sodium silicate). An improved stone, called Apœnite, is made from the malm rock of Surrey, a pale cream-coloured fine-grained soft sandstone, of Upper Greensand age, containing about 40 per cent. of soluble silica, 15 per cent. of alumina, and the remainder of quartzose sand. This stone, known as Farnham stone, is mixed with sodium silicate, lime or chalk, and alumina. Insoluble silicates of lime and alumina are formed, and the liberated soda combines with the soluble silica of the

Farnham stone to form fresh silicate, which is again decomposed by more lime. The successful preparation of artificial stone depends chiefly upon the cement, which should be hydraulic. Chips of rock or quarry waste, if not too large in size, may be utilised to advantage, care being taken to avoid such as contain perishable minerals which produce stains on weathering. During the incorporation of the cement, air bubbles must be carefully excluded, and a more compact stone is generally secured by prolonged immersion in water during the setting process.

## CHAPTER XIV.

### ENGINEERING GEOLOGY.

*Water-bearing Strata—Movement of Water in Rocks—Rules for Determination of Water-line—Rock Structure and Yield of Springs—Water Supply—Water Prospecting—Geological Distribution of Water-bearing Beds.*

*Water-bearing Strata.*—The engineer is continually confronted by an important series of problems in connection with water supply, the geological aspect of which it is now proposed to consider. As is well known, the rainfall upon the surface is disposed of partly by surface drainage into the streams and rivers, partly by evaporation, and partly by percolation into the ground. It is with this latter part that the following pages are chiefly concerned.

In England, the amount which is thus absorbed into the ground does not average more than one-third of the total rainfall, varying considerably in different localities according to the nature of the rock, the climate and the season of the year: the maximum is reached in the winter months, and the minimum in the summer. This subterranean water is stored up in the underlying rocks, in which it is held up by the non-permeability of certain strata, the overflow reappearing at the surface in the form of springs, or escaping into the river channels which intersect the water-logged beds. The alternation of permeable and impermeable rocks is, therefore, one of the first conditions upon which water supply depends.

Permeabilitv is a purely relative term, all rocks allowing the passage of water to a greater or less degree. This transmission of water takes p'ace partly through the pores of certain rocks, or capillaries, as they may be termed, and partly through more or less open fissures.

The *water-yielding* rocks, often called permeable, include gravels, sands, sandstones, chalk and fissured limestones; while the *water-retaining*, or impermeable rocks, are clay, marl and compact crystalline rocks. Even clay beds are not always destitute of water-yielding power: the London Clay, for example, contains occasional sandy seams, from one of which the famous Epsom medicinal spring arises; and in Suffolk many wells, sunk in boulder clay, yield a fair quantity of water owing to the presence of occasional patches and seams of sand.

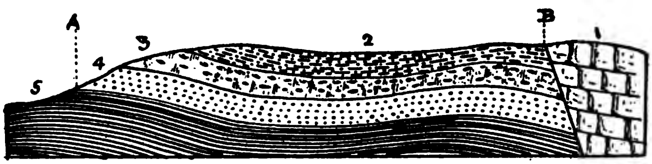



FIG. 142.—SPRING AT THE JUNCTION OF PERMEABLE AND IMPERMEABLE BEDS.

1, Chalk; 2, Purbeck Beds; 3, Portland Stone; 4, Portland Sand; 5, Kimmeridge Clay; B, Fault; A, Spring.

Percolating water, in obedience to gravity, settles down to the lowest possible level in permeable strata, reappearing in the form of springs, flowing, as will be more fully explained hereafter, either by simple gravitation or by hydrostatic pressure. Springs, therefore, are merely the overflow of underground water through suitable channels, which are mainly determined by the following geological conditions:—

(1). Springs often mark the junction of a permeable bed and an underlying impermeable bed. This occurrence is especially common on hill sides (see Fig. 142), the water issuing by simple gravitation. Similar springs often issue from superficial beds of sand or gravel (see Fig. 143).

(2). Underground water may be forced by hydrostatic

pressure to ascend through joint planes and other natural fissures; as, for example, in the case of the Giant Spring, Montana, issuing from a fissure in limestone rock.

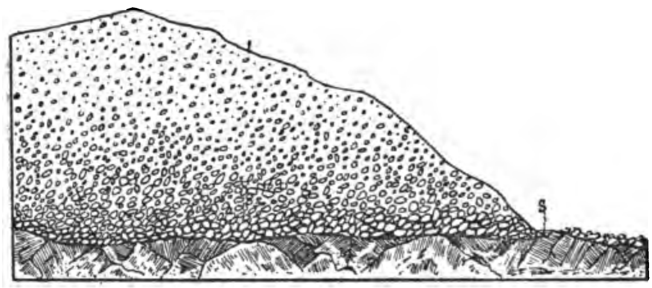



FIG. 143.—SPRING ISSUING FROM A BED OF GRAVEL LYING UPON IMPERMEABLE ROCK. S, Site of Spring.

(3). A head of water under pressure may be caused by the obstruction of a natural dam, caused by a fault or an igneous dyke (see Figs. 144, 145). Faults filled with

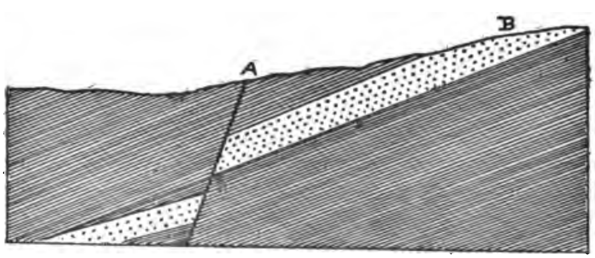



FIG. 144.—FAULT CAUSING A SPRING AT A, which is at a lower level than the outcrop B.

clay are a common cause of springs of this kind in the Carboniferous Limestone of Gower, as well as in Derbyshire and the Mendip Hills.

In all cases of natural springs surface irregularities are

indispensable, for the source must necessarily be at a higher level than the outlet: even when a spring bursts out on a hill top, the pressure must be derived from higher ground at a distance. In flat districts the overflow from saturated rocks spreads over the surface in marshy swamps.

*Movement of Water in Rocks.*—If a block of dry chalk be half immersed in a vessel of water, it will be found, after some time, that the lower half has absorbed about 35

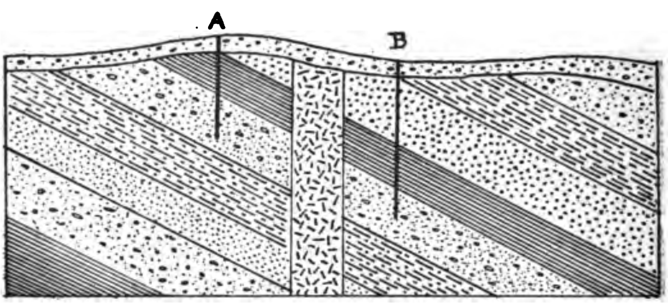



FIG. 145.—WATER IN PERMEABLE STRATA DAMMED BY AN IGNEOUS DYKE.
Water is found at A, on the outcrop side of the dyke, a boring at B being useless.

per cent. of water, while the top half has soaked up, by capillary attraction, 19 per cent. only. If a hole be made about three parts through the block, water will stand in the hole at the level of saturation, the capillary water, also called *water of imbibition* or "quarry" water, having no influence upon it.

The saturation level, or water-line in the block of chalk, is, in this case, obviously a horizontal plane coinciding with the wetted contour. If, however, more water be gradually poured over the top of the block, it will slowly sink to the lower portion, escaping slowly at the saturation level into the surrounding vessel, and causing the

water-line to assume a dome shape in the centre. This *curvature* of the water-line is a necessary consequence of the equilibrium of the forces of gravity, capillarity and frictional resistance.

The limit of saturation in rocks is governed by the level of the lowest natural point of escape; as, for example, the sea-level, if the permeable bed reaches the coast line; or the level of any streams flowing in the

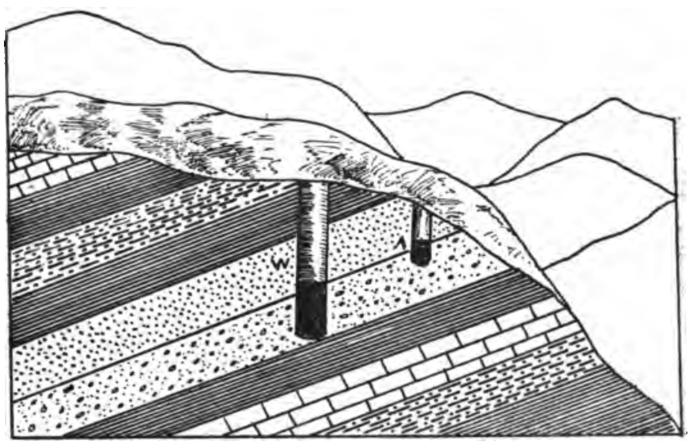



FIG. 146.—UNDERGROUND DRAINAGE IN AN OPPOSITE DIRECTION TO THE SURFACE SLOPE.
W, Well contaminated by cesspool A.

river valleys intersecting the permeable stratum. Rules will presently be given for drawing the water line under various geological conditions.

The general direction of movement of underground water will follow the dip of the permeable beds, and is often, therefore, in an opposite direction to the slope of the surface, a point often overlcoked in fixing the relative position of wells and cesspools (see Fig. 146). In addition to the slow percolation through the capillaries

and interstices of the rock, there will also be a more rapid movement through any fissures, faults, joints and well-defined bedding planes. This latter movement may considerably modify the general circulation, since there will always be a tendency to choose the easiest path. The capillary or interstitial movement is often not sufficiently fast in compact rocks, such as chalk or sandstone, to be available for pumping from a small bore-hole, so that the success of tube-wells, sunk in such strata, will depend upon tapping a fissure in which there is a freer circulation.

The underground circulation is also influenced by pumping from a well or bore-hole sunk into the water-bearing stratum. The effect of continuous pumping is to produce a temporary *cone of depression* around the bore-hole, as shown in Fig. 147, the *rest level* being shown in adjacent bore-holes at a height depending upon the hydrostatic pressure in the water-bearing bed. This cone of depression produces an indraught from the whole surrounding area, part of which movement must be in the opposite direction to the general dip of the beds. A cesspool in porous strata may, therefore, contaminate a well, however it may be situated with reference to the dip, if it is sufficiently near to be within the influence of the cone of depression produced by pumping.

In the water-logged sands of the Inferior Oolite, the radius of the cone of depression, after 12 months' continual pumping at a rate of about 1,800 gallons per minute, was found to extend 200 yards from the pumping centre. In no case is the general water level of the water-bearing stratum *sensibly* influenced by pumping at any one point. In general, the radius of the cone of depression will vary inversely with the facility with which the water circulates through the water-bearing stratum. It must be clear also that the surface of the cone of depression will in no case be a true cone, but an

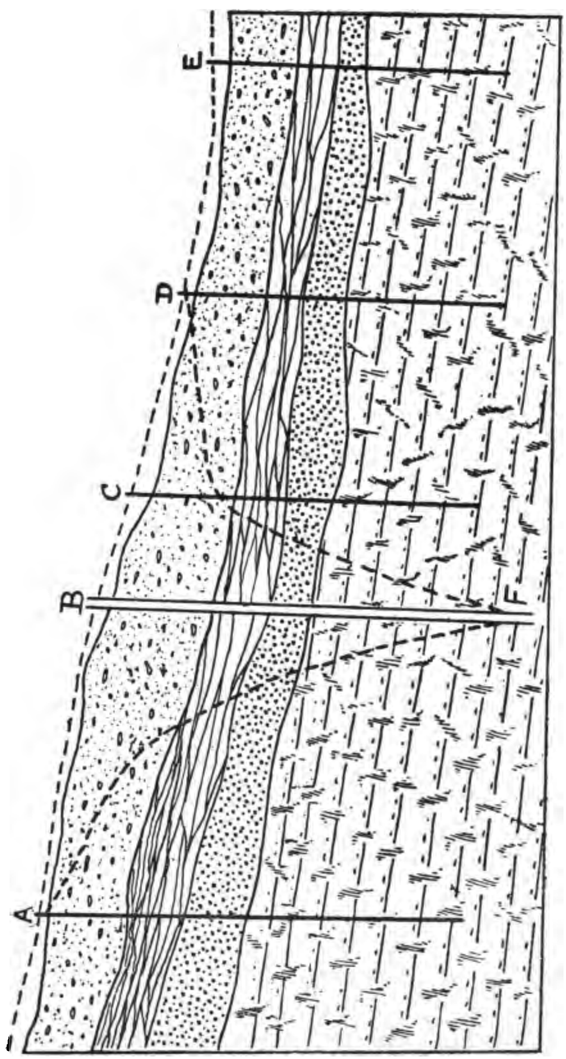



FIG. 147.—CONE OF DEPRESSION PRODUCED BY PUMPING FROM A BORING, B, SUNK IN CHALK
The dotted line A B C D E shows the rest-level of the water in adjacent boreholes.
The curve A F D is the cone of depression.

irregular curve depending upon the texture of the rock and the number of fissures intersected. Unless the pull of the pump be very great, the curve of depression will be almost inappreciable.

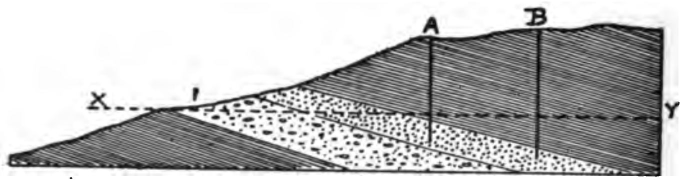



FIG. 148.—WATER-LINE (Case 1).
Water in boreholes at A, B, will rise nearly to the level X Y.

*Rules for Determination of the Water-line.*—The depth of wells and the height to which water will rise in a bore-hole are each regulated by the position of the level of saturation, although frictional resistance prevents the water issuing from springs or bore-holes from reaching

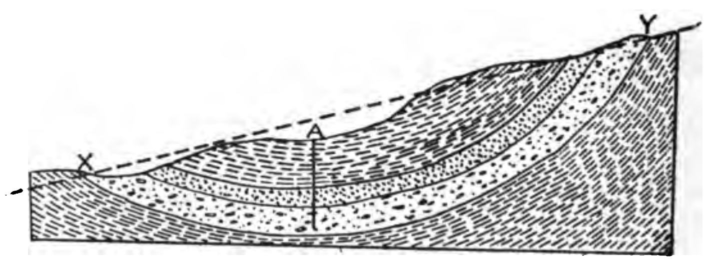



FIG. 149.—WATER-LINE (Case 2).
Water in borehole at A will rise nearly to the level of X Y.

the theoretical height to which hydrostatic pressure would otherwise force it. In determining the position of the water-line, the following cases may commonly occur:—

*1st case.*—When the water-bearing stratum dips between two impermeable beds so that the permeable

bed is saturated throughout its entire thickness, the water level will be a horizontal line through the nearest point of the outcrop (see Fig. 148). Water will consequently stand in bore-holes at A, B nearly at this level.

*2nd case.*—When the water-bearing stratum reappears at the surface in a synclinal curve, the water level is a line joining the two points of outcrop, as A, B, Fig. 149.

*3rd case.*—If the permeable stratum is very thick, and not saturated throughout its entire mass, the underlying impermeable beds being above the valley levels, the water-line is a curve rising from the lower boundary of the permeable bed and falling to the same boundary at each valley intersection, the height of the arch depending upon the amount of rainfall on the outcrop of the permeable beds and the rapidity of percolation (see Fig. 150).

*4th case.*—If in the above case the underlying impermeable beds are below the valley levels, the water-line falls to the river levels, as in Figs. 151, 152. Dry upland valleys are above the saturation level.

*5th case.*—If the water-bearing bed reaches the coast, the water-line rises from the lower boundary of the permeable bed and falls to the sea-level (see Fig. 153).

The crown of the arch may rise 60 to 80 feet above the chord, the slope of the curve varying between 3 feet and 30 feet per mile according to the rainfall fluctuations. Dry seasons flatten the curve, and lower the head of water to an extent which varies directly as the permeability, and inversely as the imbibition and storage capacity of the rock.

*Rock Structure and Yield of Springs.*—Both the *quality* and *quantity* of the water issuing from springs and wells are influenced by the geological conditions under which it occurs. The influence of the soluble constituents of the strata through which water percolates, is sufficiently well shown by the chemical analyses of spring waters from various sources; and the cause of the differences

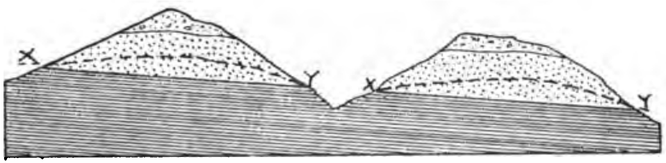



FIG. 150.—WATER-LINE Case 3).
The curve X Y of the saturation level is diagrammatically exaggerated.

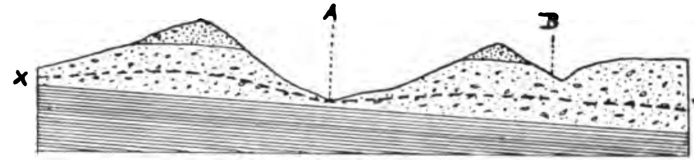



FIG. 151.—WATER LINE (Case 4).
A, River valley; B, Dry upland valley; X Y, Water-line.

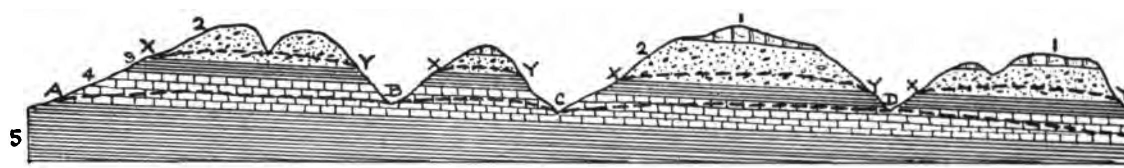



FIG. 152.—SPRINGS AND STREAMS IN THE YORKSHIRE OOLITES AND THEIR RELATION TO THE SATURATION LEVELS X Y AND A B.
1, 2, Corallian series; 3, Oxford Clay; 4, Kellaways Rock; 5, Estuarine Shales.

observed is to be found in chemical reactions, which have already been alluded to in previous chapters of this work. The hardness of water from calcareous rocks, the frequent presence of soluble protosalts of iron from ferruginous rocks, the presence of gypseous springs and sulphuretted hydrogen as a result of the decomposition of pyrites, are familiar examples. The enumeration of all the varieties of mineral springs, although of the utmost practical importance, cannot be attempted here, as this subject is generally sufficiently well treated in the elementary text-books. One point, however, may be noticed as illustrating the uncertainty which characterises the quality of the water even from a single geological formation. It has been found that the water from the chalk, where the latter is covered by the London Clay formation, contains less lime salts and more salts of soda and potash than where the chalk is not so covered. The reason for this peculiarity is not obvious, unless it is the result of the dilution of the hard chalk water by an influx of the softer water from the overlying Tertiary strata. Variations in the quality of water are also produced by the completeness of the oxidation of organic matter during filtration through porous rocks. The quantity of water available in any water-bearing stratum depends primarily upon the rainfall at the outcrop and the thickness of the stratum. The yield of a spring or bore-hole is also largely influenced by the presence of fissures, below the water-line, through which there is free circulation. Many bore-holes, sunk into the Middle and Lower Chalk in the London area, have failed where dug wells have been successful, owing to the greater chance offered by the larger area of a dug well of encountering fissures, which in this part of the chalk are few and uncertain. To increase the number of fissures tapped by the well, horizontal galleries, or adits, are sometimes driven for short distances below the plane of saturation in the

chalk. The reason is obvious. The joints and fissures offer free passage to the water stored up in the capillaries, through which it passes too slowly to be available for pumping.

The delivery of water, in fact, varies greatly in rocks of different kinds. Sands have a quick delivery, unless the pores are choked by the presence of argillaceous impurity; the storage capacity is also large. Fissured limestone rocks also have a copious and free delivery; but the storage is deficient, and the supply is liable to fail in times of drought. Rubbly oolites have a free and regular delivery, with good storage capacity. Chalk has a slow, permanent and often copious delivery, its storage

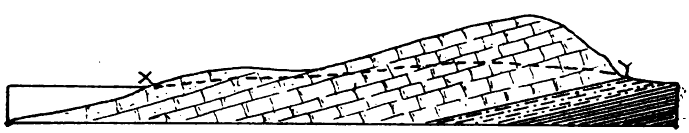



FIG. 153.—WATER-LINE (Case 5).
X, Sea-level; Y, Boundary of Permeable Bed

capacity being great on account of the resistance to free motion in its capillaries. It has been estimated that it requires from four to six months for the rainfall to reach the saturation level, and that the maximum effect of a drought is not felt until after a lapse of sixteen months. The enlargement of fissures and cavities by the continual solution of chalk and limestone, tends to increase the water-yielding capacity of such rocks as pumping continues. It has been shown that the yield of certain wells in limestone rocks is rapidly affected by *swallow* holes, or fissures which engulph streams flowing over the surface. This disappearance of streams is a common phenomenon in the Coral Rag district of Oxfordshire, in the sandy Cornbrash of Somersetshire, in the Chalk area of the London basin, and in the Carboniferous Limestone

districts of Gower, the Mendips and Derbyshire. In Yorkshire it has been found that a temporary stopping of these swallow holes by artificial dams, caused many of the wells in the neighbourhood to become dry in a few minutes, and after a period of fourteen days a very wide area was affected.

*Intermittent* springs flow freely for a time and then cease, the flow beginning again after an interval of rest. The explanation of this phenomenon is to be found either

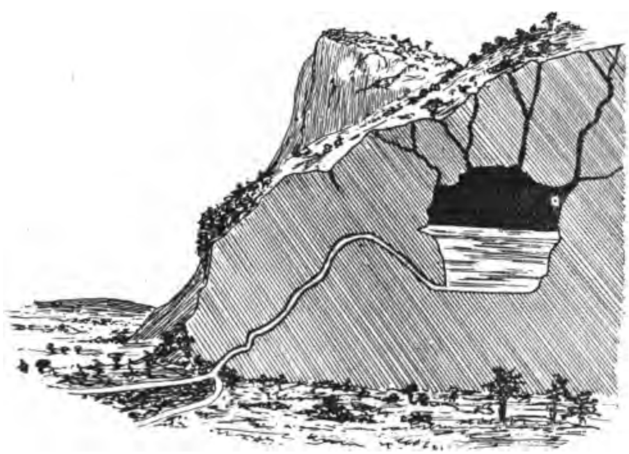


FIG. 154.—THE SIPHON THEORY OF INTERMITTENT SPRINGS.

in fluctuation of the water level, or in a siphon-like fissure, communicating with a cavity, fed by other fissures, as shown in the diagram, Fig. 154. Prestwich explains that the same siphon-like action may result from the ridge of an anticlinal curve in the porous bed being lower than the outcrop. Wells situated near the sea not uncommonly show regular fluctuations with the rise and fall of the tides. This may be due to a rise and fall in the water-line, as shown in Fig. 155, owing to the

fresh water being dammed back by the sea-water. The well wave in these cases usually lags behind the tidal wave, on account of the frictional resistance offered by the rock. If such wells are over pumped, the cone of depression thus produced may cause an influx of salt water, a phenomenon which has been noticed in the Goldstone well at Brighton.

The yield of a well sunk near the edge of an escarpment is liable to be more or less uncertain, on account

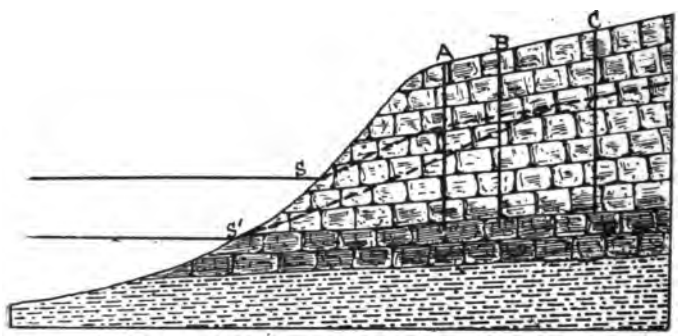



FIG. 155.—TIDAL WELLS.
**S, S', Levels of high and low water; A, B, C, Wells in which the tidal fluctuation of the water-level gradually diminishes at a distance from the sea.**

of the fluctuation in the curve of the water-line combined with the general circulation of the underground water in the direction of the dip, and consequently away from the face of the escarpment. Where perennial springs of unusual magnitude occur in such a situation, as at Lydden Spout, near Folkestone, it is possible that the strata may be bent under the escarpment, as in Fig. 161, the curve acting as a dam, and thus increasing the yield of a spring situated at C.

New wells sunk to a low level may drain those situated at higher levels, if the latter communicate with the former

by means of fissures or faults. This actually occurred in the case of the Green Lane and Bootle wells, situated 3½ miles apart, sunk by the Liverpool Corporation in Triassic sandstones. Similarly, when the fault in the Millstone Grit was cut into by the Bradford Corporation, Skipton Moor, a mile distant, was thereby drained.

In calculating the storage capacity of a water-bearing bed, it must be remembered that this is not the same thing as the amount of rainfall annually *absorbed.* Fully saturated rocks have acquired their water by centuries of rainfall; but if more than the annual rainfall is ab-

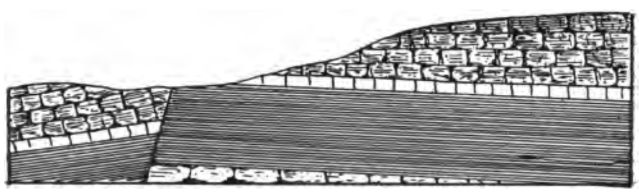


FIG. 156.—INFLUENCE OF A FAULT ON THE STORAGE CAPACITY OF A WATER-BEARING STRATUM.

stracted, the level of saturation must be permanently depressed. The following table is the calculated volume of water which certain typical rocks are capable of holding when fully saturated:—

| | | | |
|---|---|---|---|
| Sand | 2 | gallons per cubic foot. | |
| Chalk | 2 | ,, | ,, |
| Bath Oolite | 1·25 | ,, | ,, |
| Magnesian Limestone | 1·75 | ,, | ,, |
| Compact Sandstone | ·625 | ,, | ,, |
| ,, Pebble Beds | ·733 | ,, | ,, |
| Granite | ·185 | ,, | ,, |

It is evident, however, that these are only approximate values, since variations of texture must exert a great

influence upon the storage capacity of even similar kinds of rock.

The storage capacity may also be influenced by faults and underground flexures. Thus, in Fig. 156, the permeable strata are interrupted by a fault, which not only cuts the subterranean water into two detached portions, but also throws out springs at the junction of the clay. In Fig. 157, the storage capacity is similarly diminished by the fault at A, owing to the interruption to the continuity of the permeable strata.

*Water Supply: (a) Surface Springs.*—The foregoing remarks will now be further illustrated by a short description of their application to questions of water supply in some typical localities. In former times, before any serious attention was given to questions of sanitation, water from shallow wells, sunk in alluvial gravels or superficial beds of sand, was almost exclusively relied upon, even in large cities. The growth of cities situated upon clay formations was, therefore, largely regulated by the position and extent of these gravel patches. The sections shown in Figs. 158 and 159 represent the condition of both London and Oxford, the clay formation in each case rendering impossible any other source from shallow wells than the inadequate and dangerous supply furnished by these superficial sands and gravels.

*(b) Deep Wells.*—There are two classes of deep wells depending upon the position of the water-bearing formation. Where this comes to the surface, it is only necessary to sink a well below the line of permanent saturation, as seen in Fig. 160, in the districts of Rochester and Maidstone, where wells sunk, as at C, D, or E, will tap the water stored up either in the Chalk or Lower Greensand. There is very little difference between these wells and the above-mentioned surface springs except in the matter of depth, and there is the same risk of contamination if the rock is fissured. Wherever water-bearing for-

FIG. 157.—SECTION FROM THE POLDEN HILLS THROUGH THE GLASTONBURY TOR.
1, Midford Sands; 2, Upper Lias Clay; 3, Middle Lias; 4, Lower Lias Clay; 5, Lower Lias Limestone; 6, Rhaetic Beds; 7, Keuper Marls.

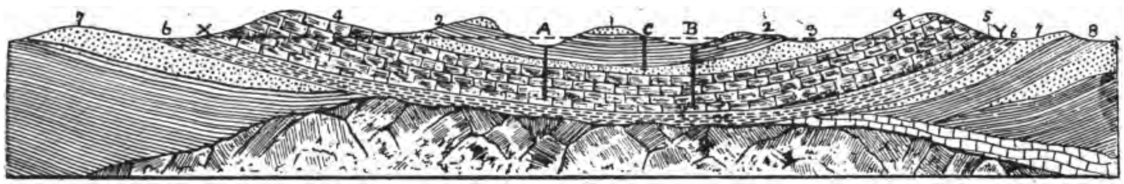


FIG. 158.—SECTION THROUGH THE LONDON BASIN.
1, *Bagshot Sands*; 2, London Clay; 3, *Woolwich and Reading Beds and Thanet Sands*; 4, *Chalk*; 5, Upper Greensand; 6, Gault; 7, *Lower Greensand*; 8, Weald Clay. The chief water-bearing strata are in italics.

mations are exposed at the surface, however, such wells form the chief source of water supply.

Where a water-bearing formation is overlaid by impermeable beds, borings, sunk through the latter into the underlying permeable strata, will intercept the water which has percolated from the outcrop, often at a considerable distance, and, therefore, more likely to be free from sewage contamination. This condition of things is clearly shown in the accompanying diagrams. In the London area (Fig. 158) deep wells are sunk either into the Lower Tertiary sands or into the Chalk—preferably the latter, on account of the limited supply in the comparatively thin Tertiary strata. Attempts to sink still deeper wells, to intercept the Lower Greensand which crops out beneath the Chalk to the north and south of London, led to the important discovery that this formation is cut out by a ridge of Palæozoic rock, and is, therefore, unavailable in the immediate neighbourhood of the metropolis. Successful attempts to reach the Lower Greensand have been made, however, nearer the margin of the London basin, as shown by the Windsor boring (Fig. 161), and the Rochester boring (Fig. 160). Other successful deep borings are shown in the diagram (Fig. 162) of the Vale of Pickering, in which the water of the Corallian beds of the Jurassic rocks, held up by the underlying Oxford clay, and dammed by the fault at F against the Kimmeridge clay, is intercepted by the boring at A. It is interesting to note that, just as the great unconformity beneath London led to the failure to reach the Lower Greensand beds, so here, in the Vale of Pickering, the success of the boring is largely influenced by the position of the fault. In the diagram (Fig. 159) a boring is shown through the Oxford clay into the Lower Oolites beneath, a very similar condition prevailing in parts of Lincolnshire (Fig. 163), where the Lincolnshire limestone and Northampton sands yield a prodigious quantity of water

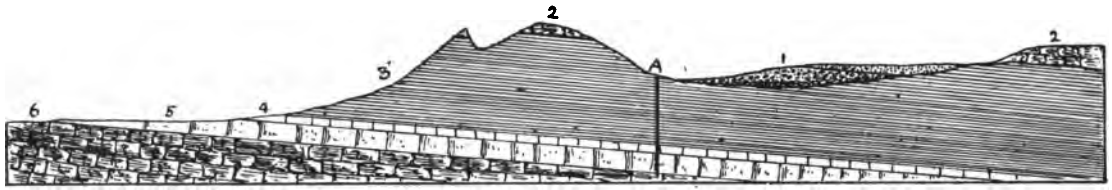



FIG. 159.—SECTION THROUGH OXFORD.
1, Superficial Gravels; 2, Corallian beds; 3, Oxford Clay; 4, Cornbrash; 5, Forest Marble; 6 Great Oolite; A, Wytham boring.

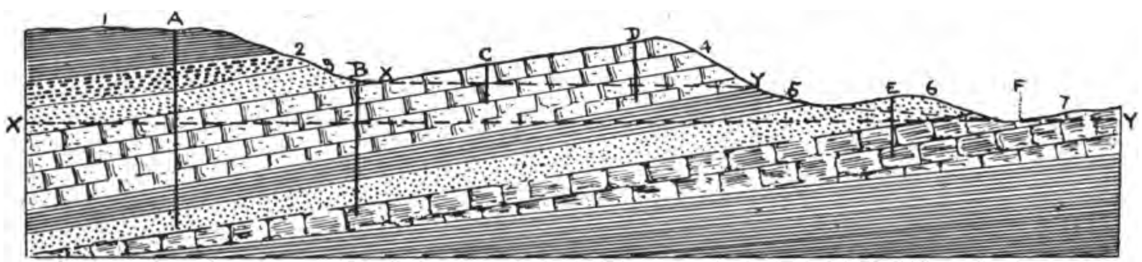



FIG. 160.—SECTION THROUGH ROCHESTER (B) AND THE MEDWAY (F).
1, London Clay; 2, Woolwich and Reading beds; 3, Thanet Sands; 4, Chalk; 5, Upper Greensand and Gault; 6, Lower Greensand; 7, Kentish Rag; XY, Saturation Lines.

reached by several deep borings, and thrown out in copious springs at the junction of the Lias clay, as at A.

(*c*) *Artesian Wells.*—A careful examination of the borings shown in the above-mentioned diagrams, together with the height of the water-line X Y, will show that the rest level of the water in the boring is sometimes above the surface of the ground, and is nearly always considerably above the level at which the water-bearing formation is tapped. Only those borings from which water overflows at the surface used to be called *artesian;* but this term is now generally taken to include all borings in which the rest level is higher than that at which the water-bearing stratum is reached. The reason for the hydrostatic pressure which forces the water up the boring to its rest level has already been explained. The actual height which the water reaches is never quite the theoretical height, owing to the large amount of friction in the water-bearing rock.

The most favourable situation for artesian wells is shown in the London basin section (Fig. 158), where the water-bearing Chalk formation rises well above the general surface level of the London area. Synclinals are, however, by no means essential for overflowing artesian wells; monoclinal strata will also produce the necessary conditions, provided that the outcrop of the water-bearing bed lies at a sufficient elevation above the top of the boring. In all cases, the height to which water will rise in a boring at any spot is determined by the level of the water-line, constructed in the manner already described.

The possibility of successful artesian borings in arid districts, such as Western Australia, is one of the most important problems in applied geology.

In all deep borings, the temperature of the water is likely to be higher than that found in superficial beds. The temperature of the famous Grenelle well is about

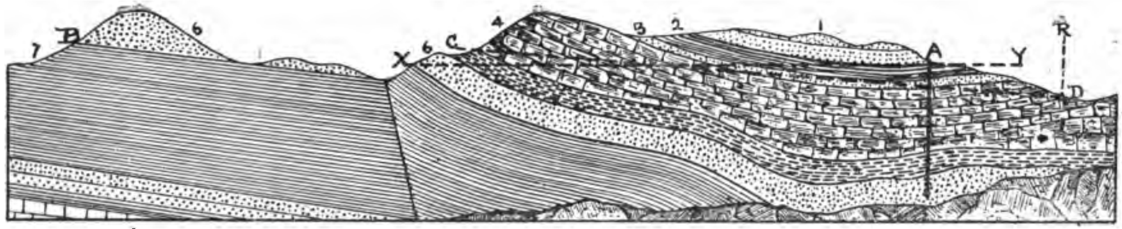



FIG. 161.—SECTION THROUGH LEITH HILL AND WINDSOR.
1 Bagshot Sands; 2, London Clay; 3, Lower Tertiary beds; 4, Chalk; 5, Upper Greensand and Gault; 6, Lower Greensand; 7, Weald and Atherfield Clays; XY, Saturation Line in the Lower Greensand; CD, Saturation Line in the Chalk.

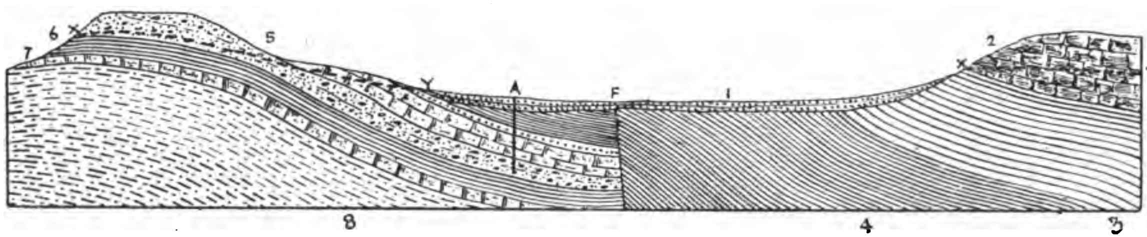



FIG. 162.—SECTION THROUGH THE VALE OF PICKERING.
1, Drift; 2, Chalk; 3, Neocomian; 4, Kimmeridge Clay; 5, Corallian; 6, Oxford Clay; 7 Kellaways Rock: 8, Estuarine Shales; F, fault; A, site of the Irton boring.

$82^{\circ}$ F., while that of the water from some Cornish mines, at a depth of 1,750 feet, varied between $86^{\circ}$ F. and $92^{\circ}$ F. Local causes produce, however, great variations in the temperature of undergronnd water.

*Water Prospecting.*—To undertake a deep boring for water without previously ascertaining the geological structure of the locality is a proceeding which has resulted in the waste of a great deal of money. Unfortunately, favourable geological conditions have not always been productive of success, on account of unsuspected unconformities, faults, flexures or thinning out of the water-bearing beds. This uncertainty has perhaps been the chief cause of the still prevalent belief in the divining rod.

The chief points which the water prospector will endeavour to determine may be summarised as follows :—

1. He will draw a *section* through the locality from a geological map having a scale of not less than six inches to the mile. The length of the section must be sufficient to include the outcrops of any *permeable* strata dipping beneath the locality in question. The sections shown in this chapter are necessarily diagrammatic.
2. The *thickness* of the permeable beds, their *breadth of outcrop*, and their *dip*, will thus be accurately known, as well as the depth below the surface at which they will be reached by a boring.
3. There must also be an *impervious* bed below the water-bearing formation to hold up the water in the latter.
4. The *rainfall* on the outcrop of the permeable strata must be estimated, since no artesian boring can supply permanently a larger volume of water than these beds receive by the annual rainfall.
5. The *water-line* must then be drawn according to the rules already described. By this means the rest level of the water in the boring will be known, as well as its relation to the surface contour.

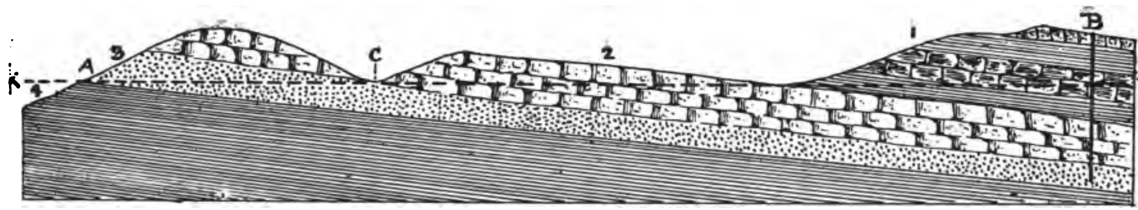



FIG 163.- SECTION THROUGH THE LINCOLNSHIRE OOLITES.

1, Great Oolite 2, Lincolnshire Limestone; 3, Northampton Sands; 4, Lias Clay XY, Saturation Level
A, springs; C, river valley; B, boring.

6. The presence of intervening *faults* or *igneous dykes* must be determined as accurately as possible, as well as the position of underground *flexures* and *unconformities*. It is here that the great uncertainty of hydrogeological problems exists.
7. The possibility of the *thinning-out* of the water-bearing beds must be considered. For instance, the Upper Greensand, an important water-bearing stratum in Wiltshire, is reduced below London to a few feet of impermeable argillaceous sand. The oolites, also, thin out considerably when traced eastwards from the Cottswolds.
8. The accuracy of deductions should be carefully tested by reference to any existing wells and borings in the neighbourhood.
9. The known geological peculiarities of the particular water-bearing stratum should be taken into account, so far as these are likely to influence the character of the water supply as regards hardness, or the presence of abnormal quantities of soluble matter generally.
10. The liability to sewage contamination must not be overlooked. This danger is greatest when the permeable bed forms the surface of the locality in which the well is sunk. Fissured limestone rocks and porous sands and gravels quickly absorb surface drainage. In too many cases, the contents of cesspools are deliberately allowed to soak away into the very beds from which the water supply is derived. Attempts have been made to prove a connection between typhoid epidemics and fluctuations in the height of the water-line: it is certain that a large range of fluctuation increases the danger of pollution. The danger of organic pollution is diminshed when the water-bearing bed is cut off from the surface by an intervening impervious stratum, or when the organic

matter has been decomposed by the oxidising processes accompanying filtration through a sufficient thickness of compact rock.

*Geological Distribution of Water-bearing Beds.*—It now remains to examine briefly the main features of the water supply derived from the different geological formations.

The *Post-Tertiary* water-bearing beds consist chiefly of alluvial and drift sands and gravels of no great thickness, from which water can usually be obtained by shallow wells. Even the boulder-clay of Suffolk yields a fair supply of water, owing to the boulders, stones and occasional seams of sand which it contains. In the Vale of Pickering (Fig. 162) these superficial drifts are so disposed that there is pressure enough, on boring through the superficial boulder clay, to force the water to the tops of the houses, thus forming shallow artesian wells. Peat is also a water-retaining rock of considerable importance on the elevated moors and uplands of this country, and gives rise to copious streams of a characteristic yellow colour, owing to the large amount of vegetable organic matter which is present. The preservative influence of peat upon imbedded animal remains is well known, and peaty water possesses similar stability and resistance to organic decomposition, for which reason it was once preferred for use in ships' tanks. The water from superficial deposits is usually soft, but is liable to contain a high percentage of organic matter; while wells sunk in shingle deposits near the shore are liable to become brackish in dry weather. The safest superficial water supply is that which is obtained from sands or gravels protected from surface contamination by a considerable thickness of brick-earth or boulder-clay.

*Tertiary* strata in the London and Hampshire basins contain alternations of permeable and impermeable beds specially adapted for the retention of moderate supplies of water. The Bagshot sands, for example, throw out

numerous springs at their junction with the London clay, and the Woolwich and Reading beds and Thanet sands are available for water supply, as already shown in Fig. 158. Their storage capacity is, however, inadequate for large supplies.

*The Chalk* formation is remarkable for the rapidity of its absorption of the rainfall and the consequent scarcity of streams where it forms the surface. Both evaporation and surface drainage are here reduced to a minimum, and the percolation may amount to as much as half the annual rainfall. The water in the chalk, however, appears to be very unevenly distributed. The failure of many deep borings into the *Middle* and *Lower Chalk* seems to point to the small number of fissures in this portion of the Chalk formation, the capillary water with which the rock is saturated not moving fast enough for a pumping supply. In the preliminary portions of the Channel tunnel, driven 2,300 yards in the Lower Chalk beneath the sea, very little water was encountered. It is in the *Upper Chalk with flints* that the numerous joints and fissures offer free passage to the water and yield the most certain supply.

Chalk water contains about 26 grains per gallon of solid matter, of which 14·8 is temporary hardness and 4·5 permanent hardness. Except where contaminated by means of open fissures communicating with the surface, prolonged filtration through thick layers of chalk has conferred a high degree of organic purity upon deep well water from this source.

Numerous springs break out at the junction of the chalk and the impermeable chalk marl lying beneath it.

*The Upper Greensand* of the Blackdown Hills, Devonshire, throws out an abundance of water at its junction with the underlying marls and clays, but towards the east this formation thins out and ceases to be an important water-bearing bed.

*The Lower Greensand* throws out springs, as at Leith Hill and Hind Head (see Fig. 161), at its junction with the Atherfield clay. This stratum furnishes an abundant supply of water both north of the London area, as in Cambridgeshire and Bedfordshire, as well as on the flanks of the Weald. The Folkestone and Sandgate beds yield soft water, often somewhat ferruginous; but the Hythe beds, being calcareous, often impart as much as 20 degrees of hardness to the water from this source.

*The Wealden* district is occupied by the Weald clay and Hastings beds formation. In the Weald clay but little water is to be found, except such as is stored up in the few seams of sand or limestones which are intercalated in the clay. The Hastings beds contain the Ashdown sand, which occupies a large extent of high ground exceptionally favourable for the supply of water to wells sunk into it at lower levels. These waters are often chalybeate.

*The Oolites* are scarcely surpassed by any other formation for the quantity and quality of the water which is stored up in the numerous beds of sandstone and limestone which characterise this formation. The sections shown in Figs. 159, 162, 163, sufficiently show the general structure of Oolitic districts. The repeated alternation of permeable strata with impermeable clays causes abundant springs and watercourses, of which Fig. 152 is a typical example. Although the water is usually hard, it is of exceptional purity except where the wells are polluted by surface contamination, a danger which is increased by the extreme porosity of many of these rocks.

*The Lias* is, generally speaking, non-water-bearing. The small quantities obtained in the argillaceous limestone of the Lower Lias is hard, and often contaminated with sulphuretted hydrogen derived from the decomposition of pyrites. In the Middle Lias occasional sandy

beds yield a small supply of chalybeate water. In many localities, situated upon the Lias, the only source of water is in the thick coating of glacial sands and gravel which frequently obscure the outcrop of this formation. Lying immediately beneath the water-bearing oolites, abundant springs often mark the junction, and are valuable sources of water supply for Liassic districts. Several natural springs rise through the Lias clays, being forced up through cracks and fissures from deep lying sources. Of this nature are the mineral springs of Bath and Cheltenham.

*Triassic* rocks supply water to many large towns in the Midlands, such as Birmingham, Leicester, Nottingham, Wolverhampton, Stoke and Burton-on-Trent, as well as Liverpool and the valley of the Exe. The gypsum beds in the Keuper marls render the water from this source permanently hard, the sulphate of lime being often present in the proportion of 100 grains per gallon, upon which quality depends the superiority of Burton beer. The Middle Keuper Sandstones, or Waterstones, contain an abundance of good water, from which the majority of New Red Sandstone districts obtain their supply. In the Tyne and Tees basins several attempts to utilise New Red Sandstone water have failed, owing to the presence of brine springs. The South Staffordshire Waterworks derive their supply from a tunnel in the New Red Sandstone, from which the water is pumped. It is noteworthy that the construction of this tunnel dried up all the wells in Lichfield until they were deepened to the level of the tunnel.

*The Permian* Sandstones are water-bearing, as also is the Magnesian Limestone. The water from the latter, however, contains a larger amount of permanent hardness than that from Chalk and other Limestone formations. Sunderland and Durham obtain their supply from this formation.

*The Palæozoic* rocks, generally speaking, become less absorbent in proportion to their age and metamorphism. In consequence, they shed the larger part of the rainfall in streams and rivers, except where the water is impounded in lakes and reservoirs, or held in peat mosses or superficial drifts. The *Carboniferous Limestone*, however, yields abundant springs where the water is dammed by clay faults, and notable examples of springs from this formation occur at Holywell, in Flintshire, in the moorlands of Yorkshire, and the hot springs of Buxton, Matlock and Clifton. *Millstone Grit* is pervious, and throws out many springs at its junction with the underlying shales in the deep valleys of Yorkshire and Lancashire. The *Coal Measures,* consisting of alternating pervious and impermeable beds, yield water of inferior quality, much impregnated with iron, and a source of continual trouble in mining operations. The influence of faults in isolating these water-bearing beds has already been noticed.

The *Old Red Sandstone* of Hereford and Monmouth furnishes an abundance of well water, the alternation of clay and sandstone being especially favourable for its retention at a moderate depth.

The *Older Palæozoic* rocks do not possess any importance as water-bearing beds, although shallow and deep wells are occasionally sunk into them with success. Even such non-absorptive rocks as granite and gneiss occasionally retain a considerable supply of water in their decomposed portions. Such accumulations of water, however, are only found in isolated patches, and in no case do they resemble the continuous sheets which move slowly through the permeable strata. The construction of "impounding reservoirs," by which large stores of water are collected from suitable gathering grounds for the supply of large towns, will be referred to in the following chapter.

# CHAPTER XV.

## ENGINEERING GEOLOGY—*Continued.*

*Impounding Reservoirs — Embankments — Tunnels — Cuttings — Road Stones—Paving Stones.*

*Impounding Reservoirs.*—In the more elevated districts of the British Islands, situated upon the older and less permeable rocks, it is often impossible to obtain enough water for large communities by means of wells or bore-holes. In such cases, given a sufficient rainfall and a suitable gathering ground, recourse is had to impounding reservoirs. Thus Dublin obtains its supply from Vartry, in the Wicklow Hills, Glasgow from Loch Katrine, Manchester from Lake Thirlmere, Liverpool by impounding the waters of Vyrnwy valley in an enormous artificial reservoir, while Plymouth has recently secured a similar supply from Dartmoor. Various geological considerations influence the choice of a site suitable for the construction of such reservoirs. It is not enough to estimate the supply of water which can be obtained in this manner by merely calculating the area of the watershed and the minimum annual rainfall; for experience shows that the proportion of the rainfall which can be collected in this manner varies from one-third to about four-fifths, according to the geological character of the underlying rocks. Thus every area has a geological drainage, in addition to the surface drainage, both of which are not always available for the district in question. Thus, in Fig. 164, the rainfall in the valley A is to a large extent carried away by the permeable bed, 2, beyond the water-parting into an adjoining valley B. The water thus abstracted from one drainage area augments, by means of springs, the supply in another

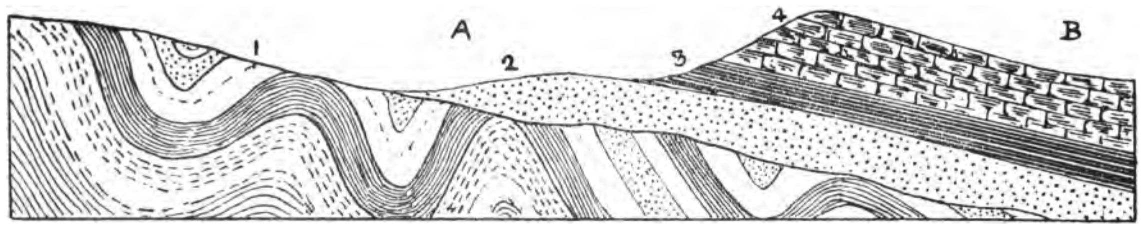



Fig. 164.—Influence of Geological Drainage on River Systems.
1, Impermeable strata; 2, Permeable Sandstone; 3, Clay; 4, Limestone.

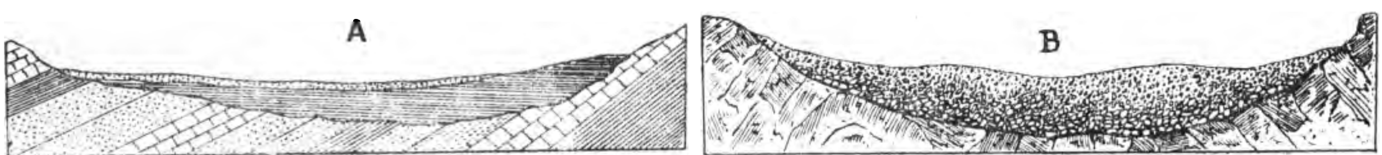



Fig. 165.

drainage area. A large drainage area may, on this account, have a much smaller available water supply than a small drainage area fed by springs from an adjoining basin.

Another point of practical importance is the nature of the superficial accumulations, which not infrequently cover the underlying rocks to a considerable depth. During the glacial period many of the river valleys were buried beneath thick accumulations either of impermeable boulder clay, or of porous gravels and sands, many of which still remain, and wholly or in part obscure the course of the preglacial rivers. The presence of these deposits may be either favourable or otherwise to the construction of reservoirs. Thus, in Fig. 165, the valley A, although excavated in porous rocks, is so completely covered by boulder clay that very little water can escape by subterranean drainage; while in B the presence of a thick coating of absorbent gravel completely spoils what would otherwise be an almost perfect natural reservoir.

Lastly, it must not be forgotten that, although surface waters collected in storage reservoirs are generally pure and soft, yet they may be rendered objectionable for domestic use by the presence of peaty matter, or by contamination from agricultural manures.

*Embankments.*—Glacial débris occasionally forms a natural dam by which water is impounded. Of such natural reservoirs Llyn Idwal, see Fig. 166, is a familiar example. More often, however, an artificial embankment is necessary, as well as puddling with clay, to prevent the escape of water. For the latter purpose some clays are not suitable, especially the Fuller's earth varieties, which readily break down and disintegrate under the influence of water.

In the construction of artificial embankments for reservoirs great care is necessary, not only for the prevention of loss of water, but also on account of the

danger of floods in the event of any portion of the barrier breaking away.

Embankments for roads and railways are usually made of loose material, and their slope and width depend upon the natural *angle of repose* of the rock of which they consist. The stability of the foundation depends upon the geological character of the underlying rock. In marshy alluvial tracts the weight of an embankment may cause a slow settling of the foundation, which may continue for months or even years. The *dip* of stratified rocks also affects the stability of an embankment. Roads and railways frequently follow the con-

FIG. 166.—NATURAL DAM, FORMED BY GLACIAL MORAINE, LLYN IDWAL.

tours, and, therefore, coincide with the *strike* of strata; but occasionally it is necessary to run with the dip. In this case the weight of the bank may force the strata along the bedding planes, causing a succession of slips, and necessitating pile-driving and timbering. The danger of such slips is diminished by beginning the embankment well ahead and working backwards towards the rise of the beds.

*Tunnels.*—In no department of engineering is geological knowledge more essential than in the driving of tunnels, a fact often realised to his cost by the contractor. The style of working, the form of the tunnel, the necessity of lining, and consequently the expense, all vary with the nature of the rock encountered. The following table

of comparison of the average cost per lineal yard of some well-known tunnels through various rocks is instructive.

COST OF TUNNELLING IN VARIOUS ROCKS.

| NAME OF TUNNEL | LENGTH | NATURE OF ROCK | COST PER LINEAL YARD |
|---|---|---|---|
| | | | £ |
| Bletchingley ... ... | 1,324 yds. | Weald Clay .. | 72 |
| Saltwood ... ... | 954 „ | Upper Greensand | 118 |
| Buckhorn Weston ... | 739 „ | Kimeridge Clay ... | 72 |
| Lydgate ... ... | 1,332 „ | Coal Measures ... | 30 |
| Honiton ... ... | 1,350 „ | Red Marl and Greensand ... | 50 |
| Netherton (Canal) ... | 3,036 „ | Marl ... ... | 39 |
| Totley ... ... | 6,229 „ | Coal Measures ... | 76 |
| Cowburn ... ... | 3,702 „ | Yoredale Shales ... | 73 |
| Kilsby... ... ... | 2,398 „ | Oolite Sandstone | 125 |
| Box ... ... ... | 3,123 „ | Oolite Limestone | 100 |
| Thames ... ... | 400 „ | Alluvium ... ... | 1,137 |
| Loch Katrine (Canal) | 2,325 „ | Slate and Old Red Sandstone ... | 11 |
| Mont Cenis ... ... | 7·6 miles | Schist and Gneiss | 167 |
| St. Gothard ... ... | 9·26 „ | Granite, Gneiss and Schist ... | 116 |

The great differences in the expense of tunnelling shown in the above table were the result partly of the nature of the rocks encountered, and partly of the difficulties caused by tapping springs and water-logged quicksands. Compact crystalline rocks may often be left with vertical sides unprotected by masonry. Thus, the St. Gothard tunnel, Fig. 167, is left with the rock walls unprotected in the granite and gneiss, but the schists required lining with masonry, being often so friable that hand labour was substituted for machine work. The peculiar fan-shaped arrangement of the rocks caused great variability both in the nature of the walls and in the amount of water encountered, some

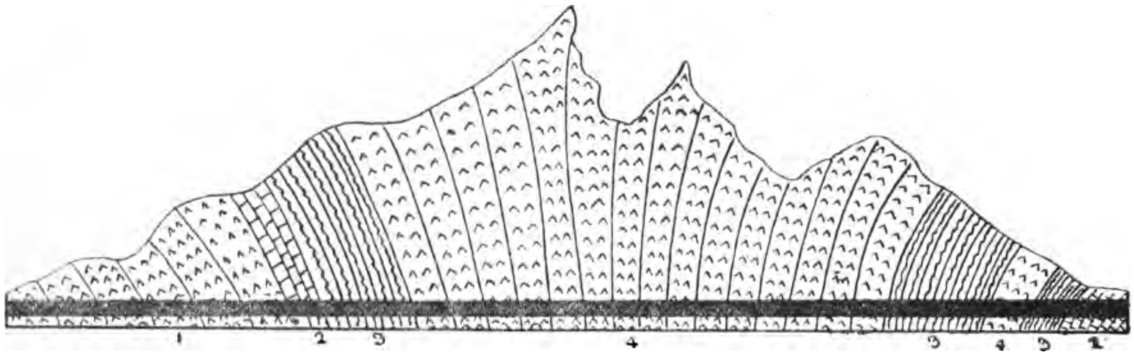



FIG. 167.—ST. GOTHARD TUNNEL, SHOWING FAN-SHAPED STRUCTURE.
1, Granitic Gneiss; 2, Crystalline Limestone and Dolomite; 3, Mica Schist; 4, Gneiss.

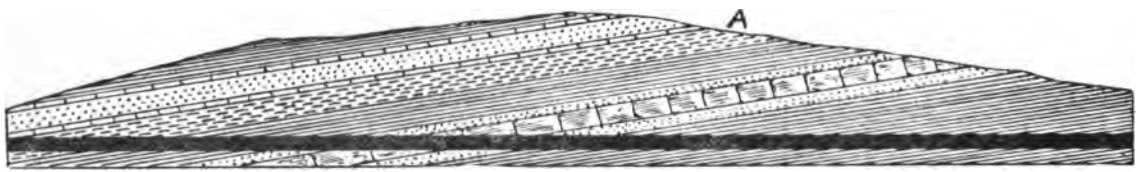



FIG. 168.—BUCKHORN WESTON TUNNEL, THROUGH KIMMERIDGE CLAY. A, Water-bearing bed, drained by a top heading.

sections being absolutely dry, and others discharging a considerable quantity of water from fissures.

In the case of the Mont Cenis tunnel, the cost was considerably greater, partly on account of the more variable nature of the rocks, the rate of advance being impeded by the difficulty of extracting the drills from the soft, decomposed rocks, which were continually being encountered. Boring operations are always more easily conducted in homogeneous rocks, however hard these may be, than in variable material. The Mont Cenis tunnel passed through Carbonaceous schist (1·3 miles), Quartzite (·24 miles), Limestone and Dolomite (·22 miles), and Calcareous schist (5·8 miles).

In the Simplon tunnel, provision was made to suit the variable rocks met with, by modifying the arch as follows:—

1. In compact rock, regularly stratified, no lining is used.
2. In irregular strata, lining and arch in ashlar.
3. Where there is moderate vertical pressure: side walls in ashlar and arch in dressed stone, 20 in. thick.
4. Under strong vertical pressure: side walls of coursed masonry and arch in dressed stone, 24 in. thick.
5. In decomposing rock, with lateral pressure: as above, with the addition of an invert.

Even in compact rock disintegration of the walls may result from chemical decomposition, when opened up to the influence of the air. Shales, which require blasting when first opened, often fall to powder by atmospheric decomposition, especially if pyrites is present. Pockets of loose material in compact rock require special care. In the construction of the Watford tunnel, through the Upper Chalk, many gravel pipes were intersected, one of which fell in and overwhelmed ten men; loose calcareous veins in the mica-schist of St. Gothard were also a frequent source of trouble.

Clay presents a peculiar difficulty, owing to its liability to expand and bulge when exposed to the air. This difficulty is known also in well-sinking and mining, the sides of wells often bulging inwards, until the well is almost closed, and the clay floors of old mines tending to swell upwards. Tunnels through clay must generally be quickly supported by timbering. The Primrose Hill tunnel, through London clay, was only saved by arching immediately with bricks, set in quick-setting Roman cement, which hardened before the pressure of the bulging clay accumulated to a dangerous degree. Fig. 168 shows a section along a tunnel driven through Kimmeridge clay, in which contraction of the heading, owing to the swelling of the clay, was also a source of trouble.

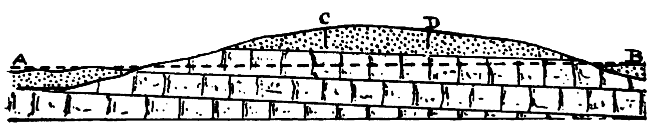



FIG. 169.—DECEPTIVE INDICATIONS OF SHALLOW TRIAL BORINGS AT C, D.

Trial borings, made along the line of a proposed tunnel, do not always afford adequate information of the difficulties which may be encountered. Thus, in Fig. 169, borings at C and D may run entirely through sandstone, whereas a tunnel from A to B would be in limestone rock. Hills also are often composed of synclinal strata, in which the tunnel successively pierces different beds, in ascending order, towards the centre of the tunnel. (See Fig. 170). The failure of trial borings was well exemplified during the construction of the Kilsby tunnel, in which enormous difficulty was encountered in the water-logged sandstones of the Inferior Oolite, often veritable quicksands, necessitating the continuous action of a line of steam pumps to maintain a

trough of dry sand in the line of the tunnel. The trial borings had missed these strata, and the tunnel, contracted for at £40 a yard, actually cost £125 a yard in consequence of this trouble.

Tunnels through coal-measures are often complicated by faults, as seen in the section, Fig. 171, through the Totley tunnel of the Midland Railway, in which difficulties were encountered by tapping springs, from which rushed water, accompanied by tons of sand, silt and

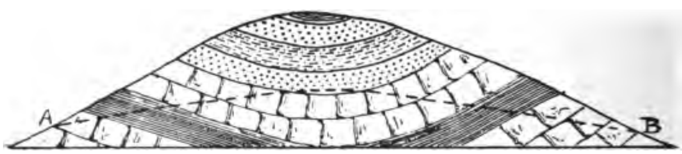



FIG. 170.—BORING IN SYNCLINAL STRATA.

stones; the large quantity of foul air in such strata, also, necessitates ventilating shafts in close proximity. Even in comparatively impermeable strata, water in large quantities may be unexpectedly met with. In the Buckhorn Weston tunnel, Fig. 168, through Kimmeridge clay, a bed of loose rock, marked A in the figure, let in so much water that a top heading was found necessary to carry it off.

Subaqueous tunnels are particularly liable to cause trouble from the irruption of water and running sand. Examples of such tunnels are found in the Hirnant tunnel, carrying the Vyrnwy aqueduct under the Mersey to Liverpool, the Blackwall tunnel below the Thames, and the Hudson tunnel, designed to connect New York with New Jersey, and constructed entirely through alluvial silt at enormous trouble and expense. (See Fig. 172).

*Cuttings.*—The slope of a cutting for a road or railway depends upon the nature of the rock which is traversed,

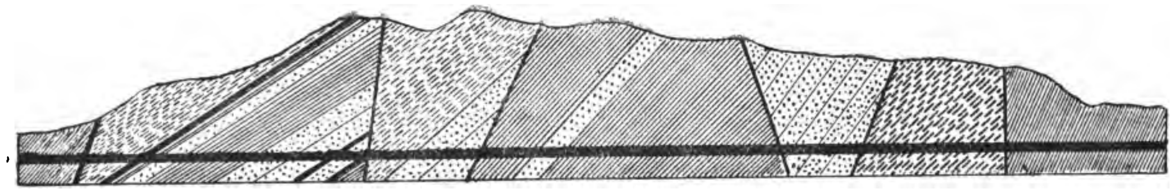


Fig. 171.—Totley Tunnel, Midland Railway (Length 6,229 yards) through Faulted Coal Measures.

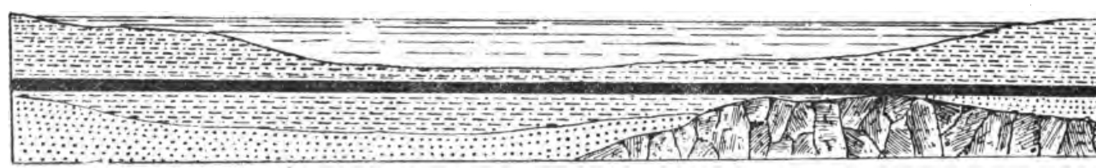


Fig. 172.—Hudson Tunnel, New York, through Subaqueous Deposits of Alluvium.

the stability of the face of the cutting varying according to the natural angle of repose of the rock material. Some compact rocks, such as chalk and close bedded

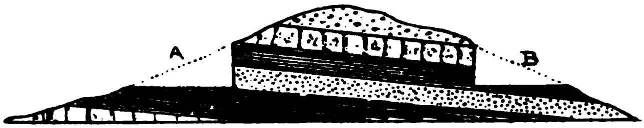



FIG. 173.—ROAL CUTTING IN SIDE OF HILL.

sandstone, will stand with an almost vertical face, while softer clays, shales, sands, or gravels, require flatter slopes, varying from 15° to 45°, according to their cohe-

FIG. 174.—VARIATION IN SLOPE OF CUTTING IN FAULTED STRATA.

sion. The results of weathering upon the sides of the cutting must also be considered, and water-bearing strata must be provided with an outflow through the retaining walls.

Horizontal strata, or beds dipping away from the face of a cutting, are more stable than those which dip towards it. If, therefore, a choice is possible in cutting through the side of a hill, as in Fig. 173, it is preferable to select the upper side of the dip, as at A, rather than the lower side, as at B, on account of the liability to landslips. This is more especially the case in water-bearing strata, liable to throw out springs on the face of the cutting B. Cuttings, in dipping strata, should be

FIG. 175.—SLOPE OF CUTTING DETERMINED BY JOINT PLANES.

well benched back towards the rise, or faced up with retaining walls. Fig. 174 shows the variation in the slope of a cutting rendered necessary by the faulted junction of Carboniferous Limestone with Lower Lias Shales.

The presence of joints also may modify the angle of slope, which should coincide with the joint planes, as shown in Fig. 175.

*Road Stone.*—Nowhere has the geologist received more assistance in investigating the structure of the earth's crust, than in the innumerable quarries which were

opened in former times wherever hard materials were available for mending roads. The indiscriminate use of any hard rock which may lie conveniently to hand is now, however, gradually being abandoned. Greater facilities, both in the transit and breaking up of road materials, enable the better kinds of stone to be more largely used, and restrict the use of the inferior materials to by-roads and country lanes.

A good road-stone should possess the following qualities :—

1. *Hardness*, or resistance to abrasion.
2. *Toughness*, or resistance to crushing or breaking when struck.
3. *Durability*, or resistance to weathering and disintegration.
4. *Binding Properties* sufficient to prevent the road from working loose in dry weather.
5. *Freedom from tendency to wear smooth*, by which foothold and ease of traction are influenced.
6. *Cleanliness*, which involves freedom from dust and mud ; this quality depends in a great measure on 1, 2, and 3.
7. *Suitability* to the locality to which it is used. A carriage-drive, for instance, requires different material from the busy thoroughfares of a large city.

It is almost impossible to judge of the value of road-stone with certainty without actual trial ; but certain physical tests are useful for comparison of the relative value of materials of different kinds. These tests are as follow :—

*The absorption test*, which consists in weighing dried samples of stone before and after immersion in water. The more absorptive stones disintegrate readily during frost.

*The weathering test*, which may be carried out as already explained under the head of Building Stones.

*The abrasion test*, performed either by subjecting a given weight of broken stones to rapid revolution in a cylinder; or by pressing samples against a grindstone; or better, a ribbed iron cylinder to reproduce the effects of vehicular traffic. In each case the loss by weight in a given time is noted.

*The crushing test*, in which cubes of stone are subjected to the action of a hydraulic press, and the crushing pressure noted.

*The drop test*, in which a known weight is allowed to fall repeatedly upon the sample, the number of blows required to break it and the dust produced being determined. A 15 lb. hammer, with a 10-inch drop, may be used for this purpose.

The results of some road-stone tests are now given, not on account of their absolute value, but as illustrating the variation shown by some of the best known samples when submitted to physical tests.

1. *Results obtained by Mr. T. Clark, Truro District Council.*

| | Hardness | Specific Gravity | Tenacity, *i.e.*, No. of blows in drop test. | Dust produced from a 3-lb. sample in ounces |
|---|---|---|---|---|
| Greenstone (Gweek) ... | 6·5 | 2·95 | 800 | 11 |
| Gneiss (Porthallow) ... | 6·5 | 3·0 | 566 | 6½ |
| Quartz ... ... ... | 7·0 | 2·27 | 265 | 12½ |
| Cornish Elvan ... ... | 6 | 2·3 | 894 | 12 |
| Clee Hills Basalt ... | 6·5 | 2·65 | 724 | 12 |
| Scotch Whinstone ... | 6 | 2·57 | 454 | 11½ |
| Scarborough Limestone | 6 | 2·48 | 511 | 10 |
| Schist (Cornwall) ... | 5·5 | 2·16 | 571 | 13 |
| Consolidated Ash (Askham) ... ... | 6·0 | 2·47 | 688 | 9¾ |
| Sandstone ... ... | 6·0 | 2·49 | 529 | 10½ |

2. *Results obtained in Lovegrove's Rotary Machine*, 4 lbs. of stone being submitted to 8,000 revolutions in a cylinder making 20 revolutions per minute. The tests were made both dry and with water.

| | Dry. | | | Wet. | | |
|---|---|---|---|---|---|---|
| | Loss per cent | Chips | Dust | Loss per cent | Chips | Dust |
| Granite (Guernsey) .. | 7·95 | 0 | 7·95 | 14·45 | 1·07 | 13·38 |
| Quartzite (Hartshill) .. | 6·25 | 0 | 6·25 | 8·64 | ·29 | 8·35 |
| Elvan (Cornwall) .. | 6·54 | 1·12 | 5·42 | 7·81 | ·29 | 7·52 |
| Basalt (Clee Hills) .. | 6·05 | 0 | 6·05 | 10·15 | 0 | 10·15 |
| Basalt (Antrim) .. | 10·69 | 0 | 10·69 | 24·85 | 0 | 24·85 |
| Diabase(Penmaenmawr) | 2·44 | 0 | 2·44 | 3·9 | ·14 | 3·76 |
| Trachyte (Coed-y-Glyn) | 7·32 | 1·02 | 6·30 | 8·4 | ·44 | 7·96 |
| Syenite (Leicester) .. | 4·15 | ·05 | 4·10 | 5·47 | 0 | 5·47 |
| Pennant Grit .. .. | 14·45 | 0 | 14·45 | 27·54 | 0 | 27·54 |
| Mendip Limestone .. | 10·16 | 1·22 | 8·94 | 15·43 | 2·1 | 13·33 |
| Derbyshire Limestone | 20·75 | 4·49 | 16·26 | 24·7 | 2·34 | 22·36 |
| Devonian Limestone .. | 22·8 | 6·49 | 16·31 | 37·2 | 3·56 | 33·6 |
| Magnesian Limestone .. | 13·23 | 0 | 13·23 | 30·17 | 4·34 | 25·83 |
| Kentish Ragstone .. | 17·14 | ·83 | 16·31 | 27·44 | 0 | 27·44 |
| Chalkpit Flints.. .. | 14·16 | 2·34 | 11·82 | 11·81 | 2·73 | 9·08 |
| Picked Surface Flints.. | 15·43 | 5·03 | 10·4 | 13·62 | 2·78 | 10·84 |
| Gravel Pit Flints .. | 26·17 | 15·5 | 10·6 | 15·76 | 5·12 | 10·64 |

3. *Mud-producing Tests by Prof. Elliott, Cardiff University College.*—Specimens were subjected to rapid motion of a ribbed iron cylinder acting as a grindstone.

| | Percentage of Dust produced in 4 hours. |
|---|---|
| Basalt (Clee Hills) ... ... ... | 7·2 |
| Elvan (Cornwall) ... ... ... | 7·2 |
| Granite (Wicklow) ... ... ... | 8·0 |
| Granite (Guernsey) ... ... ... | 9·3 |
| Granite (Aberdeen) ... ... ... | 15·7 |
| Limestone (Mumbles) ... ... | 20·0 |
| Granite (Cornwall) ... ... ... | 22·1 |
| Limestone (Swelldon) ... ... | 30·2 |
| Sandstone ... ... ... ... | 89·4 |

In general it is found that the efficiency of road-stone varies considerably with texture and mineralogical com-

position. Thus the *granites* must not be too coarse, and the presence of much felspar is objectionable. Hornblendic varieties, such as those of Mount Sorrel and Guernsey, are far more durable on account of the toughness of the hornblende. This influence of hornblende is well illustrated by the following figures, due to Ansted, showing the loss in weight per superficial foot after seventeen months' traffic in East London :—

| | |
|---|---|
| Guernsey syenite... ... ... ... | 4—5 lbs. |
| Mount Sorrel granite ... ... ... | " |
| Dartmoor granite ... ... ... | 12½ lbs. |
| Aberdeen grey granite ... ... ... | 14¾ " |

The Mount Sorrel granite is one of the best macadam stones in England; it is a fine-grained, compact, hornblendic variety, being hard, tough and durable, binding well, and crushing with but little waste. In Cornwall, the elvans, from their compactness, are far superior to the granites, and the granite of the Scilly Islands is too coarse for use as road metal.

The more basic igneous rocks also show great variability in this respect. Some of these quickly decompose to clay, and render the roads almost impassable with mud, while others rank amongst the best road-stone in the country. Amongst the latter class may be mentioned the Clee Hills basalt and some of the Whinstones of the North of England. The Clee Hills basalt, recommended by the Home Office in its "Advice to Surveyors" as an almost perfect road-stone, is notable for its toughness and suitability for heavy traffic, with sufficient hardness to ensure a minimum of dust and mud. Similar rock is extensively worked at Rowley Regis, Barrow Hill and Pouk Hill. The whinstone of the Cleveland dyke is an augite andesite, with a higher percentage of silica than basalt, and, in consequence, a superior durability to the diabase of the Whin Sill dyke, which decomposes into a ferruginous clay. One of the

best road-stones, however, of this class is the Penmaenmawr stone, an enstatite-diabase of fine texture and in great demand for use under heavy traffic.

On the whole, the efficiency of the igneous rocks depends upon closeness of grain and a high silica percentage, combined with a fair proportion of tough ferromagnesian constituents.

Amongst metamorphic rocks the quartzites hold the best reputation, especially when, as at Hartshill, the natural brittleness of the quartz is tempered by the presence of a small admixture of felspar. The schists, although used locally in parts of Scotland, easily disintegrate; but some of the highly siliceous slate rocks, as used at Gwennap, in Cornwall, are more durable.

The older limestone rocks are still largely used in this country, the Carboniferous Limestone from the Mendips being transported in large quantities to the neighbouring counties, and that of the North of England being sometimes preferred to the whinstone. It makes excellent roads, the mud in wet weather producing a kind of mortar, which produces an unequalled surface in summer. The Jurassic limestones, however, are gradually being abandoned, owing to the facility with which they are ground to powder, making white dust in summer, and a large quantity of soft greasy mud in winter. The marlstones are tougher and more durable, and are still in demand in parts of Somerset and Gloucester. Limestone roads have also a great tendency to lift during frost.

Sandstones cannot be recommended except where the traffic is very light. They soon pulverize under heavy traffic, and the dust has little or no binding power. Pennant Grit, and Greywether sandstone are perhaps the best, and the highly ferruginous Carstone, used in West Sussex, is fairly durable. The calcareous grits and sandstones have better binding properties, although they are not so hard, and are liable to more rapid disintegration in drought or frost.

Flints, so extensively used in the chalk districts of England, are the most durable of road material, but suffer from their brittle nature, especially when unweathered. Hence flints fresh from the chalk are almost useless for roads. Surface-picked flints and gravel flints are tougher. The binding properties of flint are almost *nil*, for which reason a better road is produced by admixture of ragstone or hard chalk. The same want of binding power characterises the pebble beds and modern pebble beaches occasionally used in the south-east of England. Chert is better than flint, being tougher and, on that account, yielding less gritty dust; but its occurrence is limited.

*Flagstones and Paving Stones* are quarried from certain thinly bedded sandstone formations, such as those occurring in the Old Red Sandstone of Caithness, Arbroath and Dundee. Of these, the first named are of close texture, and are liable to wear smooth and slippery. An uneven surface is sometimes formed by the superior resistance afforded by nodules of iron pyrites. The flagstones of Arbroath and Dundee are softer and more laminated, and consequently more absorbent. Flagstones of large size and of a durable nature are procured from the Millstone Grit and Ganister beds of Yorkshire and Derbyshire; while softer material occurs in the Permian strata of Dumfries and Cumberland, as well as in the Lower Lias of Street and Keinton Mandefield in Somersetshire, where blocks of exceptionally large size are procured. Paving stones are also procured from the Oolite and Wealden beds, but of inferior quality. The Horsham stone, a fissile calcareous sandstone in the Weald clay, is often strongly ripple marked, and hence specially adapted for the floors of stables.

The commercial value of natural flagstones is at present seriously affected by the competition of artificial paving stones made of concrete slabs, of which several varieties are now largely used.

## CHAPTER XVI.

### SURFACE FEATURES.

*Superficial Deposits—Origin of Soils and Sub-soils—Fertility of Soils—Connection between Soils and their Parent Rocks—Influence of Soil on Vegetation—Improvement of Soils—Dwelling Sites—Conclusion.*

*Superficial Deposits.*—The foregoing chapters have been chiefly concerned with the economic aspects of rocks situated at greater or less depths below the surface. There still remains to be considered the superficial covering by which the solid geology of a district is generally more or less completely obscured. These superficial deposits are often of considerable thickness, and owe their origin to a variety of causes, some of which are still acting, and all of which date from comparatively recent times. The impossibility of adequately representing upon the same map both the solid geology and the superficial drifts has led the Geological Survey of this country to prepare a special set of maps, called *drift* maps, upon which the surface deposits are shown. Surface geology has, if possible, even a wider and more universal practical application than the geology of the underlying beds. Land, in fact, has a two-fold value, superficial and mineral, a point which is sometimes lost sight of in land valuations. Estates are often sold for the mere agricultural value of the soil, or their suitability for building sites, irrespective of the possible value of subjacent minerals; while, on the other hand, a great deal of litigation has resulted from the disposal of the *solum* or soil with special reservation of mineral rights. Land valuers, land buyers and colonial settlers, therefore, should take into consideration both the superficial and mineral value of an estate, so far as these can be ascertained. The restitution or preservation of the

surface value of the land is often made a special feature of quarrying and mining leases. Thus the coprolite diggers in Cambridgeshire pay £140 an acre for digging, and have to restore the land in two years, levelled and resoiled; during which time as much as 300 tons per acre of calcium phosphate have often been extracted. The thickness of the superficial covering is also an important factor in the estimation of the quantity of overburden to be removed in quarrying.

The engineer, in dealing with questions of drainage, cuttings, and embankments, the construction of docks and harbours and the stability of foundations, is largely influenced by the nature of the surface beds. Estimates of cost have frequently been upset by an insufficient knowledge of the nature of superficial beds. Shore sands and gravels, presumably easy of removal, have been found so cemented into natural concrete as to necessitate blasting, as was the case in the construction of the Albert Dock at Leith. Dredging operations have been seriously impeded by the unsuspected occurrence of rock ledges, such as the dolomite ledges in the Wear, Carboniferous sandstone ledges in the Tyne, and greenstone dykes in the Clyde. These are only a few instances of the importance to the engineer of an accurate knowledge of the nature of the surface rocks.

The agriculturalist, again, who forms his opinion of the value of the soil from the main geological structure of the country, may find his calculations erroneous if he ignores the surface drifts, upon which the fertility of the soil chiefly depends, and by which the agricultural features of the same geological formation may be completely changed, even in closely adjoining districts.

Lastly, in these days of scientific sanitation, the soil has come in for a large share of attention in connection with the geological distribution of diseases. This subject, although still in its infancy, has an important bearing

upon the selection of residential sites, and appeals alike to every member of the community.

*Origin of Soils and Sub-Soils.*—Let us, therefore, consider first the nature and origin of these superficial accumulations. From what has already been said about the chemical changes which are continually taking place near the surface, leading to the weathering and disintegration of the various rock constituents of the earth's crust, it will be evident that, even in the absence of drift accumulations, there will still be a greater or less thickness of decomposed rock at the surface. (Fig. 177). This facts leads us to divide soils, in the first instance, into two main divisions, viz., those which have originated *in situ*, which have been variously described as ***indigenous*** or *sedentary*; and those which have been ***transported*** from a distance and spread indiscrimately over subjacent rocks of all geological ages.

The following classification will, therefore, be found convenient :—

ORIGIN OF SOILS AND SUB-SOILS.

| | |
|---|---|
| **Soils formed in situ** (indigenous or sedentary) | *Soils of disintegration.*—Produced by weathering of the older rocks near the surface. |
| | *Soils of accumulation.*—Produced by organic agency, such as peat and swamp soils, guano deposits. |
| **Soils of transport.** | *Gravitation deposits.*—Talus slopes, cliff débris, materials of landslips and avalanches. |
| | *Alluvial deposits.*—Alluvium of rivers, river gravels, coastal swamps and mud flats. |
| | *Wind-blown or Æolian deposits.*—Sand-dunes, loess and adobe, soils of arid regions. |
| | *Glacial deposits.*—Till, boulder-clay, glacial silt, glacial sands and gravels. |

There is, however, often no clear line of demarcation between indigenous and transported soils, owing to the tendency of all surface deposits to become mixed with wind-blown dust and rain wash from the hill sides. Soils of transport predominate not only in river valleys, dales,

and fens, but also in those upland districts which have been the scene of glacial action. It is only in the absence of these transported materials that soils can be expected to follow the main geological structure of a district. Thus, in Fig. 178 (p. 224), the Lias clay of Warwickshire is seen to be covered with a thick deposit of glacial drift, by which it is completely obscured.

*Fertility of Soils.*—The agricultural value of a soil is determined partly by its chemical nature and mineral

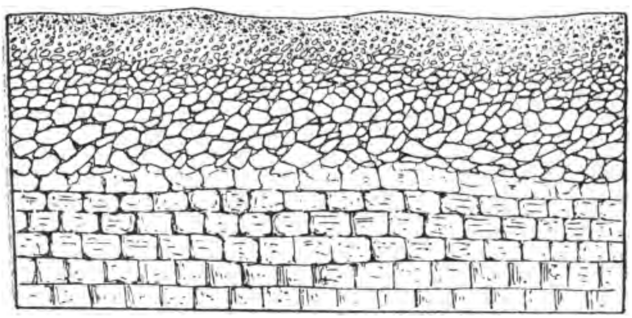


FIG. 177.—GRADUAL TRANSITION OF ROCK INTO SOIL.

composition and partly by its physical condition. Upon the chemical and mineral composition depends the quantity of available plant food, such as potash, lime, magnesia, phosphoric and sulphuric acids; while the physical condition and degree of comminution regulate porosity and capillarity, the amount of surface exposed to root action and the space available for air and moisture. Many soils contain all the constituents of plant food, but in unavailable forms; thus granite soils often contain salts of potash, lime and magnesia, locked up in the form of insoluble silicates, and only available as plant food on decomposition by weathering. Such soils, even though not prominently fertile, are still not readily

exhausted on account of the slowness with which their mineral ingredients yield to disintegrating influences. On the other hand, certain rocks, such, for example, as serpentine, which, although rich in ferro-magnesian silicates, are poor in minerals containing lime and potash, could scarcely be expected to yield fertile soils whatever chemical decomposition they may have undergone.

The older soils, also, tend gradually to become impoverished by the completeness with which both their destructible minerals, as well as their soluble decomposition products, disappear by the leaching action of percolating water. This impoverishment of the soil is also still more rapidly effected by careless or ignorant husbandry.

The most fertile soils, such as Nile mud and Chinese loess, appear to owe their remarkable powers of growing crops indefinitely, without the aid of artificial manures, to the presence, in a state of excessively fine subdivision, and comparatively unaltered, of such minerals as felspar, mica, hornblende and augite, which, by their gradual decomposition, yield the necessary food for plants, without the danger of their being washed out, owing to too rapid production.

Soils of indifferent fertility, therefore, may often be improved by admixture with others possessing the required qualities. This explains the natural fertility of many alluvial soils, and the utility of such agricultural operations as marling, liming and warping. For the same reason soils often exhibit a marked increase in fertility near the outcrop of another formation. It is said that the peculiar fertility of the hop district of Farnham is due, to a great extent, to the many outcrops, in a small area, of beds of different character, and to the consequent mixing of soils.

*Connection between Soils and their Parent Rocks.*—It is the natural tendency of all soils to lose by degrees the

characteristics of their parent rocks by the gradual removal of soluble salts, and finally to resemble one another in consisting of mere insoluble residues, such as sand and clay, the ultimate decomposition products of almost every class of rock. We shall be prepared, therefore, to find great differences in composition between the soil and its parent rock, even in the absence of any drift covering. Granite soils may indeed differ but little from their parent rock, except in mechanical disintegration, although even in this case there is generally a loss of lime and magnesia, with a corresponding increase in alumina and ferric oxide.

The basic igneous rocks, consisting of a larger proportion of the more destructible minerals, are usually covered by ferruginous clays, a notable example of which is the laterite which represents the residue left by the weathering of the Deccan trap rocks of India. The celebrated cotton soil of S. India, which bears crops year after year without artificial aid, is a similar soil derived *in situ* from the chemical destruction of basalt.

Limestone soils present the greatest differences from their parent rock on account of the solubility of calcium carbonate in natural waters. These soils often consist almost entirely of ferruginous clay, mixed with flint or chert nodules, and containing but little calcareous matter. To such an extent has the calcium carbonate been removed, that such soils are often agriculturally improved by the addition of chalk. Thus the coral limestone of Bermuda is covered with a red ferruginous clay, of which the parent rock contains barely one part per cent. Such soils represent, therefore, the removal in solution of great thicknesses of the parent rock.

The sandstone rocks yield soils of a similar nature, varying more or less with the composition of the cementing material, but on account of the chemical indestructibility of silica containing a larger proportion of sand.

The geological age of the rock upon which any particular sedentary soil rests, is not of great importance in comparison with its mineralogical character, and still less where it is covered up by thick accumulations of transported gravel, sand, or alluvium.

*Influence of Soil on Vegetation.*—The natural vegetation of any locality is so entirely dependent upon the nature of the soil, that the geologist often receives great assistance in mapping the boundary lines between different strata, from careful observations of the plants which grow there. For instance, it is most interesting to note how that beautiful heath, *Erica vagans*, which grows upon the serpentine of the Lizard district, in Cornwall, marks out the boundary of the barren serpentine from the fertile soils of the adjoining rocks. Buckland, writing in 1840, describes a moor in Dumfries, in which a band of bright green herbage marked the course of a trap dyke traversing slate rocks. Similarly, in Staffordshire, the line of junction of Carboniferous Limestone and Millstone Grit is very clearly drawn on the surface by the sudden change in the quality of the grass, and four plants in particular mark the exact spot where the soil changes—the furze, the heath, the whortleberry and the sorrel. In Hertfordshire the boundary line of the London Clay is frequently defined by a verge of grassland, which terminates with the outcrop of the chalk; while in the New Forest the presence of the taller furze is a certain indication to the farmer that the land below is worth reclaiming. In many cases, also, particular formations are characterised by the trees which grow upon them. In Surrey the Gault is distinguished by the luxuriant growth of oak and elm; while the Weald clay has long been noted for the perfection of its oaks. Beech trees abound on the chalk formation, and elms flourish on London clay, while the famous oaks of Bagot's Park, in Staffordshire, mark the position of an

outlying patch of Lias clay. It is well-known that the districts most celebrated for their cider are situated on the cornstones and marls of the Old and New Red Sandstone formations; and in Scotland, the Carse of Gowrie, famous for its apples, stretches also over the Old Red strata.

Particular weeds are often a useful indication of the fertility or barrenness of the soil. Thus poor soils grow large quantities of the common daisy, the rest-harrow, the foxglove, the yellow rattle and quaking grass; and, if sandy, poppies, blue-bottle, wall-barley and bracken. Calcareous soils produce knapweed, scabious, burnet and wild parsnip, and fertile loams grow an abundance of chickweed, groundsel, goosefoot and mustard.

Not only the natural vegetation, but also the agricultural features of a country, are dependent upon geological conditions. In England much of the contrast between the various geological formations is lost, owing to the large extent to which the underlying rocks are covered up by superficial drifts; but even here the stiff soils of the eastern boulder clays, the sheep-farming of the chalk-downs, the pasture-land on the cold clays of the Midlands, the rich Old Red Sandstone soils, and the barren aspect of the rugged Silurian rocks, are sufficiently characteristic.

In Belgium similar differences are to be observed between the desolate plateau formed by the Palæozoic rocks of the Condroz and Ardennes, the fertile Hesbayan loam of the central parts, the barren Campine sands, producing only heather and pines, and the rich alluvial soil of the Polders.

In Norway the fjelds, or elevated plateaux, which occupy more than half its area, are perfectly barren; and in Sweden the cultivated tracts coincide with the deposits of glacial clay and marl, which cover up the gneiss and granite.

From the alluvial deposits forming the two immense plains of Hungary, one of the richest soils of Europe has been formed, and the chief source of the agricultural wealth of Russia is the recent deposit known as black-earth, which occupies the valleys of the Don, Dnieper and Volga.

In America the connection between geology and agriculture is still more marked in those districts which are free from glacial drift. The sudden transition from the fertile alluvium of Virginia to the barren sands, clothed with pine forests, which characterise the Tertiary beds; the dry chalk downs and treeless prairies, famous for Georgian wheat, which mark the secondary deposits, and the general husbandry and fertile soils of the primary rocks, forming the lower slopes of the Alleghanies, show the geological features of this district almost as perfectly as would a careful geological survey of the underlying rocks. These differences are to some extent due to climate, which has as much influence as the soil in modifying agricultural operations; but climate is regulated mainly by contour, which again depends upon geological structure. So that whether soil or climate produces variations in agricultural features, there is, in both cases, the same primary cause.

*Improvement of Soils.*—The improvement of soils and the reclamation of wastes are amongst the most important problems of agricultural geology. Before waste lands can be restored to profitable husbandry, the cause of their want of fertility must be known. In many cases a fertile soil is buried beneath superficial accumulations quite unsuitable for cultivation. Thus by the removal of peat the Blair Drummond Peat Moss was converted into valuable agricultural land. The treatment of blown sand, which covers millions of acres of fertile soil in the maritime districts of Europe and America, is a more difficult matter, owing to its depth and mobile character.

Probably the most profitable method of utilising these sandy wastes is by planting them with pines and other conifers, which not only yield an annual return in turpentine and resin, but also in time produce a vegetable mould capable of cultivation.

The improvement of soils by admixture has already been mentioned, and advantage may often be taken of this method, in favourable situations, by artificial warping, or flooding at high tide with water laden with alluvial sediment. It has even been suggested that the fertilisation of the barren *landes* of Gascony should be attempted by artificial warping from the Pyrenees.

Many arid districts require extensive irrigation before profitable agriculture is possible; but in a moist climate like that of the British Isles, the soil more often suffers from an excess of water, which must then be removed by artificial drainage. Now the nature of the soil and subsoil has a considerable influence upon the arrangement of land drains, their depth below the surface, their distance apart, and their capacity. The more pervious the superficial covering, the deeper should the drains be laid; in impervious soils it would obviously be useless to place the drains so deep that the water could only reach them with difficulty. In a light soil, resting upon a bed of clay, the upper porous layer should be completely cut through, and the drain imbedded partially in the clay. When the reverse conditions hold, and the clay bed is on top, it is better to cut through the clay into the porous stratum beneath if the former is not too thick.

It sometimes happens that a clay substratum, covered by permeable sands or gravels, has an uneven surface, causing the subterranean water to be ponded between the subterranean ridges as in Fig. 179. In this case the ridge, or stank, as it is sometimes called, must be cut through, by which means a large area is often com-

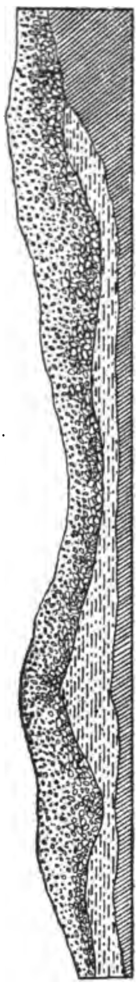


FIG. 178.—GLACIAL DRIFT IN WARWICKSHIRE.
A, Lias Clay; B, Boulder Clay; C, Glacial Gravel.

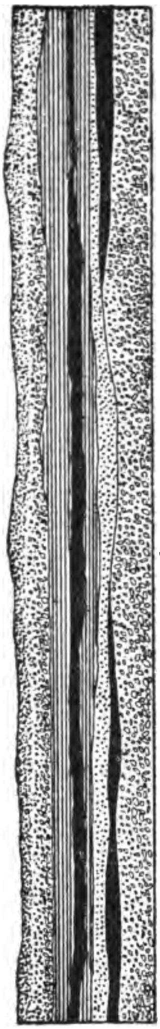


FIG. 184.—ALLUVIAL SOIL, WITH VARIABLE SEAMS OF GRAVEL, SAND, PEAT AND CLAY.

pletely drained. This is an occurrence often found in the Oolite clay districts of Oxfordshire.

The distance between the drains is also regulated by the porosity of the soil. In light sandy soils this distance may be considerably greater than in heavy clay land. In very loose soils, such as peat or running sand, in which a firm bed for the drains cannot be readily secured it is necessary to guard against sinking by laying the drains upon planks or other supports.

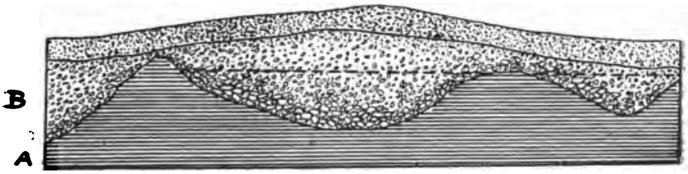



FIG. 179.—UNEVEN SURFACE OF OXFORD CLAY, CAUSING SUBTERRANEAN PONDS.
A, Oxford Clay; B, Gravels.

The size of the pipes must bear some relation to the facility with which the soil delivers its water. Sands have a quick delivery, and require larger drains than clays, which, being more retentive, only part with their water slowly.

Stony soils may give considerable trouble, not only by increasing the labour of cutting the trenches, but also by making it more difficult to lay the drains with an even gradient.

It may, in some cases, be advantageous to relieve the pressure of water in a porous stratum by an artificial spring, whereby the water may be drawn off at a suitable level, and the springs in the lower grounds thereby dried up. This method, known as *sink-hole* drainage, or Elkington's system, consists in opening a shaft into the water-bearing stratum and filling in the hole with large

stones, the water issuing from the shaft being carried off by suitable drains.

Swamps often mark the lower junction of a porous bed lying upon clay. In this case a main drain should be laid at the base of the permeable stratum, see Fig. 180. When a stiff soil overlies an extremely porous stratum, such as Kentish Rag or Chalk, artificial swallow holes, or dumb wells, are often sunk through the impermeable bed with great success. Such swallow holes are

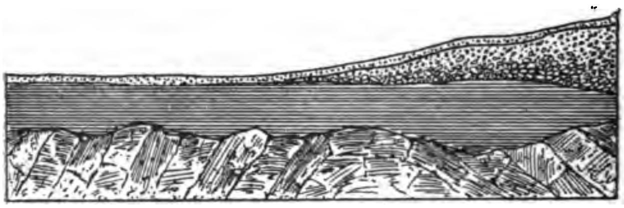


FIG. 180.—SWAMP CAUSED AT THE JUNCTION OF PERMEABLE AND IMPERMEABLE BEDS.

often useful to absorb the water carried into them by drains from the overlying impermeable beds.

Moorlands are sometimes wet and swampy from the formation of a hard ferruginous crust or pan, which prevents the escape of water. This is caused by the percolation of carbonates of lime and iron from the upper layers of the soil, and their redeposition as cementing materials in the lower parts. In such cases subsoil ploughing is often efficacious, the pan being thus broken up, and the imprisoned water being thereby enabled to percolate freely to lower levels. The formation of a pan of this nature is a common feature of red sandstone soils, and explains the frequent occurrence of fens and marshes upon otherwise permeable subsoils. Even soils formed upon blown sands are frequently wet from this cause, a notable example being the sand dunes of

the shores of the Bay of Biscay, where the natives in winter use stilts in moving through the stagnant waters imprisoned on the surface by the impermeable pan beneath.

Deficiency of water is more difficult to combat. The rainless district of the United States, forming the so-called Great American Desert, is covered by a finely divided adobe soil of great depth and remarkable fertility, needing only water to convert it into one of the most fertile spots of the earth. Soils situated upon rocks of great porosity suffer also from their excessive dryness. This difficulty characterises many of the chalk soils of England and Alabama, as well as some of the Oolitic soils of the Cotswolds, the farmers being compelled either to sink deep wells, at a great cost, or to rely upon the supply afforded by artificially constructed dew-ponds. Large areas in India and Egypt are only rendered productive by irrigation, and remains of complicated systems of canals, once used for the same purpose, are still to be traced in many Eastern districts which are now abandoned to desolation.

The above-mentioned improvements are permanent. Temporary improvements are also possible by the addition to the soil of suitable manures, and by this means crops can be grown upon soils naturally unsuited to them. But in such cases the natural barrenness soon reappears if the soil is left to itself, and its maintenance in an improved state is only accomplished by constant trouble and expense.

*Dwelling Sites.*—Building sites are often determined rather by the contour of the ground and the possibility of obtaining an adequate supply of water, than by the nature of the soil and subsoil. Clay soils retain the surface moisture and render the atmosphere both damper and colder than gravel, sand or chalk, although this defect is diminished in elevated localities with good drainage. In one res-

pect, also, clay soils are superior to those of a more porous nature, since there is less danger of contamination of the sub-soil by sewage. Thin gravel beds resting upon a clay sub-soil may be a cause of damp basements, owing to the leakage of moisture into the foundations at the junction of the gravel and clay.

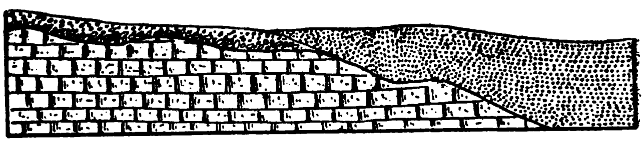


FIG. 181.—VARIABLE SUBSOIL AT THE JUNCTION OF DIFFERENT STRATA.

Porous strata, if contaminated by sewage, may be a cause of unhealthy conditions owing to fluctuations in the water level. A rise of the water-line displaces a certain amount of ground air, which, poisoned by sewer gas, may thus enter the basements of houses situated upon such strata. This has been given as the explanation of the high mortality from infantile diarrhœa at Leicester, situated upon Triassic Sandstone, as com-

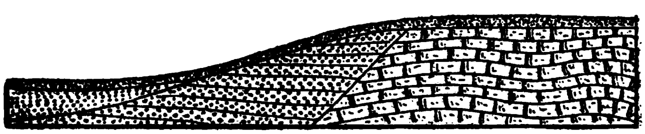


FIG. 182.—VARIABLE SUBSOIL CAUSED BY A FAULT.

pared with towns situated, as in Cornwall, on such impermeable rocks as granite and clay-slate. The sanitary conditions of various soils and the geological distribution of diseases are receiving an increased share of attention in the present day. The prevalence of phthisis in low-lying damp districts, and the reduction

both in this disease, as well as in malaria and rheumatism, which has followed the adoption of more efficient drainage, are examples of the importance of this matter to the community. In Dublin also there appears to be a marked increase in the number of typhoid cases where gravel soils permit the entry of contaminated ground air into the houses. A porous sub-soil, therefore, however desirable it may be in other respects, becomes a source of danger if care is not taken to prevent the entry into it of the soakage from sewers and cesspools.

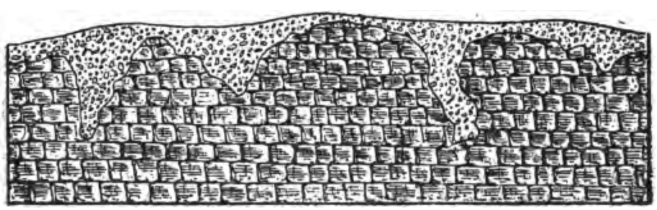


FIG. 183.—SAND PIPES IN CHALK, CAUSING UNSTABLE FOUNDATION.

In the construction of buildings the stability of the foundations is also to be considered. If the sub-soil is uniform there is less liability to an unequal yielding to pressure, and consequently to cracked walls, than if it is variable. (See Figs. 181, 182). Even solid rock is not always a safe foundation. Chalk and limestone, for example, are especially liable to contain solution cavities, and sand or gravel pipes, which may readily cause unequal settlement. (Fig. 183.) An exaggerated instance of this condition of the underlying rock is afforded by the havoc caused in parts of Cheshire by the subsidence of the surface owing to the removal of rock salt from the Keuper marls below. A deep bed of compact sand is a much safer foundation than a clay slope, since

the latter undergoes a considerable amount of shrinking in dry weather, as well as swelling after a heavy rainfall.

Alluvial deposits, consisting of gravels and sands, often water-logged, with interstratified seams of peat and clay, make an uncertain foundation. (Fig. 184, p. 224). Settlements in such situations have resulted from rapid variations in the amount of underground moisture, either owing to the presence of tidal water, or to the

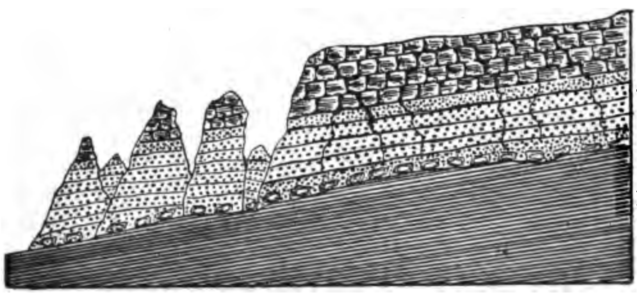



FIG. 185.—LANDSLIP NEAR LYME REGIS.
A, Chalk; B, Upper Greensand: C, Layer of Concretions; D, Lias Clay.

artificial drainage suddenly effected by railway cuttings or tunnels in the vicinity. The danger of "made ground" and rubbish scarcely needs mention.

In the selection of building sites in the vicinity of cliffs and steep valley slopes the liability to landslips must not be overlooked. The nature of the rocks and the dip of the strata should be carefully investigated. Such slips are of repeated occurrence in certain districts, and many diastrous results have followed from the selection of these sites for human habitation, without due regard to the consequences which may ensue after periods of excessive rainfall. It has already been pointed out in a previous chapter that landslips follow the dip. If, therefore, permeable and impermeable strata dip out-

wards on a hillside the conditions will favour the sudden displacement of the beds. Such slips have been frequent in Herefordshire, where heavy masses of Silurian limestone rest upon Fuller's earth or Ludlow shales; in Derbyshire, where Millstone Grit summits lie upon Yoredale shales; in Dorsetshire, where porous chalk and greensands rest upon Lias clay (Fig. 185); and in many other districts where Gault, Speeton Clay or London clay underlie permeable strata. Where hard

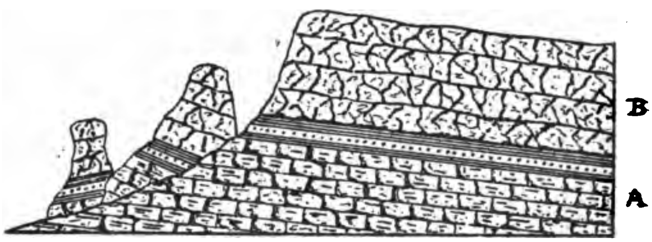



FIG. 186.—LANDSLIP CAUSED BY HARD ROCK RESTING ON SOFT, PERMEABLE STRATA, IN ANTRIM.
A, Cretaceous Beds; B, Basalt.

rocks rest upon soft permeable beds, landslips may result from the breaking away of the underlying strata, as in the case of the basalt overlying the chalk of the Antrim coast (Fig. 186).

*Conclusion.*—The application of geology to human industries, sketched in the foregoing chapters, shows only one side of the relationship between man and geology. The untiring efforts of mankind to develop the resources of the earth, have also reacted to no small extent upon those very geological processes to which he owes so much. Clearing the land for cultivation, stripping the surface of its natural vegetation, and turning up with the plough large areas of soil have materially increased the rapidity of denudation. Abundant proofs of this fact are to be found in the muddy turbid waters of

rivers, in rainy seasons, which flow through cultivated fields; those which drain unploughed lands remaining often clear and drinkable. In the Eastern United States, wherever a mountain slope has been stripped of its vegetable covering of pine forests, large ravines are rapidly formed by rain, and the clearing of the forests of the Ardèche is said to increase the effects of torrents to such an extent that many thousands of acres of fertile soil have been covered by barren sands and gravels swept down by floods from the higher grounds. Nor is this disturbing influence of man confined to agricultural processes alone. The most unexpected consequences have sometimes resulted from mining and quarrying operations. Alarming surface subsidences have often occurred in mining districts; and the reckless disposal of the waste products of hydraulic mining in America has necessitated special legislation to preserve the surface value of adjoining lands. A notable example of such unforeseen results was afforded by the removal of iron ore from Hengistbury Head in Hampshire, which led to the formation of the river bar now effectually blocking the entrance to Christchurch harbour.

Before embarking on engineering schemes, great or small, not only should the geological circumstances be considered which affect the possibility of their achievement, but also the possible results which may follow owing to the disturbance of natural processes. Man is himself a geological agent of no small importance, dependent upon nature's laws for his success in mining, quarrying, engineering and agriculture, but superior to those laws so far as he is able to modify and control them by the power of intellect.

In either case a knowledge of the laws of nature is a necessary condition of success, and to ignore them is to risk failure and court disaster.

# APPENDIX.

## SIMPLE ROUGH METHODS

FOR THE

## DETERMINATION OF MINERALS AND ROCKS.

BY J. VINCENT ELSDEN, B.Sc. (LOND.), F.G.S.

IN mining and quarrying it often happens that minerals are met with the nature of which can be roughly ascertained by simple tests. Rocks, also, can often be approximately determined from an examination of a hand specimen in the field, without resorting to elaborate chemical or microscopical methods suitable only for a well-furnished laboratory.

Of course, it is not to be supposed that these rough and ready tests are in all cases infallible, or that a more careful and minute examination can be dispensed with; but they nevertheless serve as a useful preliminary guide to the character of the specimen, and enable a more correct judgment to be formed as to whether it will be worth while to submit it to more precise investigation. The mineral, for example, may be of some possible economic value, or it may be utterly worthless. The rock may have the appearance of being a useful building stone or road stone, but its value for these purposes may be marred by some mineralogical peculiarity which is readily ascertainable.

The apparatus and reagents employed in the following tests include only such as can be readily and cheaply

procured packed in cases suitable for use either at home or in the field. Facility of manipulation will be readily acquired with practice, which should, in the first place, be obtained by experimenting with known specimens. Doubtful cases can often be settled by comparison with known types.

The method adopted in the following tables is based on the principle that the specimen either will or will not answer to a definite test, the result being that the investigator is gradually led, by the adoption or rejection of each proposition, to its final identification. Of course, it would not be possible to include every possible species in such tables as these without unduly increasing their length and complexity. A selection has, therefore, been made of those which, owing either to their more common occurrence or exceptional economic value, are of importance in practical geology.

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## SCHEME FOR THE EXAMINATION OF MINERALS.

*Table I.—The Mineral has a metallic lustre.*

1. Heated on charcoal in the blowpipe flame:—
   *a.* It gives off fumes ... ... ... ... ...
   *b.* It does not give off fumes ... ... ... 12
2. *a.* The fumes smell of burning sulphur ... ... 3
   *b.* The fumes smell of garlic ... ... ...
3. *a.* It is not scratched by a knife, but scratches glass easily ... ... ... IRON PYRITES
   *b.* It is scratched by a knife, and does not scratch glass ... ... ... ... ... ... 4
4. *a.* Its streak is not metallic ... ... ... ... 5
   *b.* Its streak is metallic ... ... ... ... 7
5. *a.* It is wholly volatile before the blowpipe CINNABAR
   *b.* It is not wholly volatile ... ... ... ... 6
6. *a.* It is brass yellow in colour ... COPPER PYRITES
   *b.* It is black or red, giving off white fumes when heated in blowpipe flame ... ANTIMONIAL ORES
   *c.* It is leaden or steel grey, fusing and giving off white fumes in the blowpipe flame ... STIBNITE

7. *a.* It is infusible in blowpipe flame MOLYBDENITE
*b.* It is fusible ... ... ... ... ... ... 8
8. *a.* It is leaden or steel grey, with cubical cleavage GALENA
*b.* It gives on charcoal a globule of silver, SILVER GLANCE
*c.* It yields a magnetic globule ... ... PYRRHOTINE
9. *a.* It is not scratched by a knife ... ... ... 10
*b.* It is scratched by a knife ... ... ... ... 11
10. *a.* It is white, metallic, massive or in flat prisms MISPICKEL
*b.* It is tin-white or steel-grey; octahedral SMALTINE
11. *a.* It has a white streak, tarnishing black... ARSENIC
*b.* It has a carmine streak ... ... ARSENICAL SILVER
*c.* It has a copper red streak ... ARSENICAL NICKEL
12. *a.* The substance is malleable NATIVE GOLD, COPPER, PLATINUM, SILVER, IRON
*b.* The substance is brittle ... ... ... ... 13
13. *a.* It is easily fusible ... ... ... ... BISMUTH
*b.* It is not easily fusible .... ... ... ... 14
14. *a.* The borax bead is coloured, CHROMIC IRON (green), MANGANESE ORES (purple), MAGNETITE (bottle green or yellow), SPECULAR IRON (bottle green or yellow), WOLFRAM (green)
*b.* The borax bead is not coloured ... ... ... 15
15. *a.* The mineral is harder than calc spar ... ... 16
*b.* The mineral is not harder than calc spar ... 17
16. *a.* It is soluble in nitric acid, and scratched by a knife ... ... ... ... ... BLENDE
*b.* It is insoluble in nitric acid, not scratched by a knife ... ... ... ... ... TIN STONE
*c.* It dissolves slowly in nitric acid when powdered, and gives a black streak ... PITCH BLENDE
17. *a.* The mineral is black ... ... ... GRAPHITE
*b.* The mineral is lead grey ... ... MOLYBDENITE

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*Table II.—The Mineral has not a metallic lustré and is insoluble in water.*

1. *a.* Streak black or coloured ... ... ... ... 2
*b.* Streak white or nearly so... ... ... ... 5

2. *a.* Heated in blowpipe flame it gives off fumes or odour ... ... ... ... ... ... 3
*b.* It gives no fumes or odour when heated ... 4
3. *a.* Colour and streak yellow, burns with blue flame ... ... ... ... ... SULPHUR
*b.* Colour orange, streak red, volatile, garlic odour ... ... ... ... ... CINNABAR
4. *a.* Borax bead is coloured purple ... MANGANESE ORES
*b.* „ „ „ green ... CHROME IRON
*c.* „ „ „ green (hot), blue (cold), COPPER ORES
*d.* „ „ „ yellow or bottle green, IRON OXIDES
5. *a.* The mineral is scratched by quartz ... ... 6
*b.* It is not scratched by quartz ... VARIOUS GEMS
6. *a.* It is soluble in nitric acid, scratched by a knife 7
*b.* It is insoluble in nitric acid, hot or cold ... 17
7. *a.* It is easily fusible in blowpipe flame ... ... 8
*b.* It is not easily fusible ... ... ... ... 9
8. *a.* It is green, yellow, or brown, does not effervesce with acid, and gives a lead bead on charcoal PYROMORPHITE
*b.* It is white or grey, effervesces with acid, and gives a lead bead when heated on charcoal CERUSSITE
9. *a.* It dissolves in cold nitric acid with brisk effervescence ... ... ... ... ... ... 10
*b.* It is soluble with difficulty in nitric acid ... 12
10. *a.* It is white, crystalline, massive or fibrous ... 11
*b.* It is yellow, red-brown or black, resinous lustre BLENDE
11. *a.* It does not crumble or powder in blowpipe flame ... ... ... ... ... CALCITE
*b.* It flies to powder in blowpipe flame ... ARAGONITE
12. *a.* It dissolves slowly in cold nitric acid ... ... 13
*b.* It dissolves with effervescence in hot nitric acid 16
13. *a.* It effervesces with cold nitric acid ... DOLOMITE
*b.* It does not effervesce ... ... ... ... 14
14. *a.* It leaves a jelly of silica ... ... SILICATE OF ZINC
*b.* It does not leave a jelly of silica ... ... 15

| | | | |
|---|---|---|---|
| 15. | *a.* | Lustre glassy ... ... ... ... | MAGNESITE |
| | *b.* | Lustre resinous ... ... ... ... | APATITE |
| 16. | *a.* | It gives a lead bead on charcoal... ... | CERUSSITE |
| | *b.* | It gives a bottle green borax bead ... | CHALYBITE |
| | *c.* | On charcoal it is yellow hot, white cold | CALAMINE |
| 17. | *a.* | It is easily fusible before the blowpipe ... ... | 18 |
| | *b.* | It is not easily fusible ... ... ... ... | 24 |
| 18. | *a.* | It is soft, waxy and greenish ... | HORN SILVER |
| | *b.* | It is not soft and waxy ... ... ... ... | 19 |
| 19. | *a.* | It swells up and melts under blowpipe | ZEOLITES |
| | *b.* | It does not swell up or melt ... ... ... | 20 |
| 20. | *a.* | Hardness, 5·0—7·0 ... ... ... ... | 21 |
| | *b.* | Hardness, 2·0—4·0 ... ... ... ... | 22 |
| 21. | *a.* | It is white, silky and fibrous ... ... | ASBESTOS |
| | *b.* | It is green or black, prismatic ... | HORNBLENDE, AUGITE |
| 22. | *a.* | It is white or grey, lead bead on charcoal | ANGLESITE |
| | *b.* | It is green or brown, resinous lustre | PYROMORPHITE |
| 23. | *a.* | It is easily scratched by quartz (H = 1—3·5)... | 24 |
| | *b.* | It is harder than heavy spar ... ... ... | 29 |
| 24. | *a.* | It splinters before the blowpipe; heavy | BARYTES |
| | *b.* | It is not heavy and does not splinter ... ... | 25 |
| 25. | *a.* | It is massive or crystallised in prisms ... ... | 26 |
| | *b.* | It is in thin scales or plates ... ... ... | 27 |
| 26. | *a.* | It is greenish, with greasy feel ... ... | SERPENTINE |
| | *b.* | It is white, with greasy feel ... ... | STEATITE |
| | *c.* | It is white, fibrous, with pearly lustre ... | GYPSUM |
| 27. | *a.* | It is in thin flexible laminæ ... ... | MICA |
| | *b.* | The laminæ are not flexible ... ... ... | 28 |
| 28. | *a.* | It has a pearly lustre and greasy feel ... ... | TALC |
| | *b.* | It is dark green ... ... ... ... | CHLORITE |
| 29. | *a.* | It flies to pieces when heated ... ... ... | 30 |
| | *b.* | It does not fly to pieces ... ... ... ... | 31 |
| 30. | *a.* | It is massive or crystallised in cubes ... | FLUOR SPAR |
| | *b.* | It is crystallised in six-sided prisms, resinous lustre ... ... ... ... ... | APATITE |
| 31. | *a.* | It is milky, never crystallised, conchoidal fracture | OPAL |
| | *b.* | It is crystallised ... ... ... ... ... | 32 |
| 32. | *a.* | The crystals are dodecahedral ... ... | GARNET |
| | *b.* | The crystals are prismatic ... ... ... | 33 |

33. *a.* The mineral is fibrous ... HORNBLENDE OR AUGITE
*b.* It is not fibrous ... ... ... ... ... 34
34. *a.* The mineral has cleavage planes ... FELSPAR
*b.* It has no cleavage planes, glassy lustre QUARTZ
*c.* It is greenish yellow ... ... ... OLIVINE
*d.* Black, becoming electric when rubbed... TOURMALINE

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*Table III.—The Mineral is soluble in water.*

1. *a.* It is coloured ... ... ... ... ... 2
*b.* It is white or colourless ... ... ... ... 3
2. *a.* Blue colour; borax bead green (hot), blue (cold), COPPER SULPHATE
*b.* Green colour; magnetic mass on charcoal ... IRON SULPHATE
3. *a.* White residue on charcoal, becoming green on reheating with cobalt nitrate... ... GOSLARITE
*b.* White residue on charcoal, becoming blue on reheating with cobalt nitrate... ... ... ALUM
*c.* White residue on charcoal, becoming pink on reheating with cobalt nitrate... ... EPSOMITE
*d.* Fuses on charcoal to liquid bead ... ... 4
4. *a.* Causes charcoal to burn vividly... ... ... NITRE
*b.* Having taste of common salt ... ... ROCK SALT

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## SCHEME FOR THE DETERMINATION OF ROCKS.

1. *a.* The rock is *crystalline*, showing a distinct granular structure, the grains being either crystals or crystalline particles, not water-warm or fragmental in appearance ... ... 2
*b.* The rock is *compact*, having a homogeneous texture, with no recognisable particles or crystals ... ... ... ... ... ... 12
*c.* The rock has a *fragmental* appearance, the component grains being either loosely aggregated or cemented into a hard mass ... 17
2. *a.* The crystals show no definite arrangement ... 3
*b.* The crystals are disposed in roughly parallel laminæ ... ... ... ... ... ... 11

3. *a.* The rock is essentially composed of one mineral species only ... ... ... ... ... 4
*b.* The rock is composed of more than one mineral 7
4. *a.* The rock can be easily scratched by a knife ... 5
*b.* The rock is not easily scratched by a knife ... 6
5. *a.* It effervesces briskly with acid ... ... LIMESTONE
*b.* It effervesces when powdered, but less briskly DOLOMITE
*c.* It does not effervesce ... ... ... GYPSUM
6. *a.* The rock is greenish, scratched with difficulty HORNBLENDE ROCK
*b.* The rock is white, yellow or red, quite unscratched by a knife ... ... ... QUARTZITE
7. *a.* The rock is holo-crystalline in texture ... ... 8
*b.* The rock has a crypto-crystalline matrix, with porphyritic crystals imbedded in it ... ... 10
8. *a.* Quartz and felspar are essential components GRANITE
*b.* Quartz is not an essential component ... ... 9
9. *a.* Hornblende and felspar are essential components ... ... ... SYENITE OR DIORITE
*b.* Striated felspars with dark crystals of augite and magnetite are present DOLERITE OR GABBRO
10. *a.* The rock shows distinct crystals of quartz ... ELVAN
*b.* The rock shows distinct crystals of felspar ... FELSPAR PORPHYRY
*c.* The rock is rough to the touch, with crystals of sanidine ... ... TRACHYTE OR RHYOLITE
11. *a.* The rock has a granitic structure ... GNEISS
*b.* The rock is fine grained and foliated ... SCHIST
*c.* The rock has a fissile structure and earthly odour when breathed upon ... ... ... SLATE
12. *a.* The rock is glassy or resinous, not scratched by a knife ... ... OBSIDIAN OR PITCHSTONE
*b.* The rock is translucent and horny, not scratched by a knife ... ... ... ... ... CHERT
*c.* The rock has a dull close-grained granular texture ... ... ... ... ... ... 13
13. *a.* The rock is easily scratched by a knife, and effervesces briskly with acid, LIMESTONE OR CHALK
*b.* It is easily scratched, but does not effervesce... 14
*c.* The rock is not easily scratched ... ... 15

14. *a*. It is white, yellow or reddish, often fibrous GYPSUM
*b*. It is white, compact, and soapy to the touch ... STEATITE
*c*. It is dark green, reddish or blotched, with soapy feel ... ... ... ... ... SERPENTINE
15. *a*. It is grey, yellowish, or bluish, rings under the hammer ... ... ... ... ... PHONOLITE
*b*. It is black or dark green; weathered crust brown ... ... ... ... ... BASALT
*c*. It is scratched with difficulty, or not at all ... 16
16. *a*. Scratched with difficulty, smooth texture FELSITE
*b*. Scratched with difficulty, rough texture TRACHYTE
*c*. It is not scratched ... ... ... ... QUARTZITE
17. *a*. The fragments are large ... ... ... ... 18
*b*. The fragments are small ... ... ... ... 19
18. *a*. The rock consists of cemented pebbles ... CONGLOMERATE
*b*. The rock consists of cemented angular fragments ... ... ... ... ... BRECCIA
*c*. Fragments are of organic origin; rock effervesces with acid ... ... FOSSIL LIMESTONE
19. *a*. The rock consists of cemented grains of quartz SANDSTONE
*b*. The rock consists of roe-like grains and effervesces ... ... ... ... ... OOLITE
*c*. The rock is extremely fine-grained, having an earthly odour when breathed upon, CLAY OR SHALE

In examining rocks it must be remembered that the precise character and name cannot always be stated with certainty from an examination of the hand specimen alone. A pocket lens will generally be necessary to determine the structure of fine-grained varieties, and a microscopic investigation is often the only trustworthy guide. The above table, however, will be useful as a preliminary step, and will be sufficient to give an approximate idea of the nature and probable economic value of the rock under examination.

# INDEX.



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